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Soil - Our endangered food base

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Contents

Foreword
M. Komac 4

Topic - Soil - Our endangered food base

Sustainable land-use alternatives in tropical rainforests? Evidence from natural and social sciences
J. Matschullat, R. Monteiro Bezerra de Lima, S. F. von Fromm, G. Coimbra Martins, M. Schneider, A. Mathis, A. Malheiros Ramos, A. Plessow & K. Kibler 5

GEMAS: Geochemistry of European agricultural and grazing land soil
A. Demetriades, C. Reimann, M. Birke, P. Négrel, A. Ladenberger, T. Tarvainen, M. Sadeghi & the GEMAS Project Team 21

Global assessment of soil pollution: The need for standardized methods
F. P.J. Lamé, K. Liphard, M. Schoemaker & T. Geßwein 33

A US Perspective on Soil Pollution: Observations, Conclusions, and Recommendations
B. P. Popkin 37

News

News corner
EFG Office 45

Book reviews 49

Peer review:
We would like to express a particular thanks to all those who participated in the peer reviewing of this issue and thus contribute to the improvement of the standards of the European Geologist journal. The articles of this issue have been reviewed by Magnus Johansson, Christos Karkalis, Luca Montanarella, Alberto Orgiazzi, Panos Panagos, Angelo Statti and Simon Wheeler.

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Foreword

EurGeol. Marko Komac, EFG President

Dear Reader,

Yet again we're welcoming you to the new issue of the *European Geologist*!

Contemporary society is facing a plethora of challenges. Some are related to societal and political challenges (like overpopulation and urban sprawl, migrations, rise of extremism, public health issues, etc.), others are trying to address technology and development challenges (like artificial intelligence, robotisation, effective utilisation of space, etc.), and finally what in my opinion is the largest group of all – the environmental challenges. These include global warming, pollution, unsustainable waste generation and its uncontrolled disposal, deforestation, loss of biodiversity, ocean acidification, ozone layer depletion, destabilisation of the nitrogen cycle, water pollution, acid rain, overfishing, genetic engineering and soil degradation, just to list the most obvious ones.

Some of the above-listed challenges have been addressed in past issues of the European Geologist journal, either directly related to contemporary environmental challenges like raw materials depletion and groundwater management or indirectly related, like geotechnical techniques for proper urban space management or geothermal energy usage. In the journal's 41st issue in 2016, sustainable land use was addressed, yet given the fact that many things have changed since that period (though unfortunately many that should have changed, haven't!) and that the focus back then was on general land use, it was decided to dedicate this issue, the 52nd, to soil deprivation, mainly from the pollution aspect. Soil represents the Earth's last solid layer, on or in which all the terrestrial life forms live, and is consequentially as important to the terrestrial ecosystems as water is. Due to growing demands for food, and current conditions of soil degradation and erosion, its preservation will be crucial in the very near future.

By addressing the domain of the soil status in different areas around the globe and presenting possibilities for its preservation, this issue of the *European Geologist* journal contributes to the acknowledgement of the importance of the soil. We hope it raises awareness that it is an important component of the bio- and lithospheres and is at the same time a limited resource that humanity shouldn't take for granted.

Despite the limited number of articles in the current issue, we strongly believe these will open unknown aspects, maybe trigger novel ideas, and lead to new ideas on how to preserve this precious media. I warmly invite you to browse through the journal, take a break from the hectic everyday pace and treat yourself to interesting reading. Thank you, and we remind you that you're cordially invited to submit articles that address any geoscience topics!

Marko Komac

Sustainable land-use alternatives in tropical rainforests? Evidence from natural and social sciences

Jörg Matschullat[1], Roberval Monteiro Bezerra de Lima[2], Sophie F. von Fromm[1, a], Gilvan Coimbra Martins[2], Mauana Schneider[3], Armin Mathis[4], Andrea Malheiros Ramos[5], Alexander Plessow[1] and Kelly Kibler[6]*

The Amazon rainforest, formerly pristine and highly biodiverse, is increasingly under threat from deforestation for cattle grazing, other forms of agriculture, mining and development. To better understand which land management type best serves sustainability aims, we compare soil gas exchange (CO_2, CH_4, N_2O) and soil chemistry for forested land with post-forest land at 13 locations and 29 sites within the state of Amazonas, Brazil. We find that forest soils show distinctively different signals and signatures compared to soils in post-forest land use cases. Crucial answers emerge regarding the limits of system resilience as well as sustainable alternatives to deforestation and current land-use practices. We carry out a socioeconomic evaluation and discuss the likely reasons for inaction and how to overcome them.

La forêt amazonienne, autrefois vierge et d'une grande biodiversité, est de plus en plus menacée par la déforestation pour le pâturage du bétail, d'autres formes d'agriculture, l'exploitation minière et le développement. Pour mieux comprendre quel type de gestion des terres répond le mieux aux objectifs de durabilité, nous comparons les échanges gazeux du sol (CO_2, CH_4, N_2O) et la chimie du sol pour les terres forestières et les terres post-forestières sur 13 sites et 29 sites dans l'État d'Amazonas, au Brésil. Nous constatons que les sols forestiers présentent des signaux et des signatures nettement différents de ceux des sols post-forestiers. Des réponses cruciales émergent concernant les limites de la résilience du système ainsi que des alternatives durables à la déforestation et aux pratiques actuelles d'utilisation des terres. Nous effectuons une évaluation socio-économique et discutons des raisons probables de l'inaction et de la manière de les surmonter.

La selva amazónica, antes prístina y de gran biodiversidad, está cada vez más amenazada por la deforestación para el pastoreo de ganado, otras formas de agricultura, la minería y el desarrollo. Para entender mejor qué tipo de gestión de la tierra sirve mejor a los objetivos de sostenibilidad, comparamos el intercambio de gases del suelo (CO_2, CH_4, N_2O) y la química del suelo para las tierras boscosas con las tierras post-forestales en 13 lugares y 29 sitios dentro del estado de Amazonas, Brasil. Encontramos que los suelos forestales muestran señales y firmas claramente diferentes en comparación con los suelos en casos de uso de la tierra post-forestal. Surgen respuestas cruciales sobre los límites de la resiliencia del sistema, así como sobre las alternativas sostenibles a la deforestación y a las prácticas actuales de uso de la tierra. Llevamos a cabo una evaluación socioeconómica y discutimos las probables razones de la inacción y cómo superarlas.

Introduction

Tropical rainforests, the dominant natural landcover in the inner wet tropics, currently cover roughly 18 million km^2 or about 12% of the Earth's land surface (3.6% of the planetary surface); about 55% of which are considered undamaged (Krogh, 2020). Intact tropical rainforests generate their own climatological and thus hydrological regimes (Marengo, 2006). High precipitation rates, coupled with large water-storage capacity and high evapotranspiration rates, trigger fast and almost permanent water recycling over these biomes (Zemp *et al.*, 2017). This is particularly true for the tropical rainforest in the Amazon basin, Brazil, which yields the world's largest integral tropical rainforest area (> 1 million km^2; Krogh, 2020). There, this cycle enables the system to sustain itself despite the fact that most soils within the biome are relatively poor in key plant nutrients (magnesium, Mg; potassium, K; calcium, Ca; Matschullat *et al.*, 2020; Quesada *et al.*, 2010; Souza *et al.*, 2018). Fast nutrient uptake by plants leads to significant in-plant storage of these elements, which become recycled into the soil upon plant decay, yet are returned rapidly into new plant growth by soil microbial metabolism (Alvarado, 2016). However, recent years have seen:

i. Reduced precipitation rates in the dry seasons, primarily to the south of the Solimões-Amazon River channel towards the states of Acre, Rondônia and Mato Grosso;

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ii. Several extreme dry seasons with next to no precipitation in June, July and August (Betts *et al.*, 2008; Jiménez-Muñoz *et al.*, 2016; Lewis *et al.*, 2011; Yang *et al.*, 2018). Such drought events should significantly impact the soil-plant-atmosphere interface (Nagy *et al.*, 2016).

Deforestation largely explains the increasing drought phenomena (Longobardi *et al.*, 2016; Phillips *et al.*, 2009; Shukla *et al.*, 1990) that are most prominent from the Transamazônica Highway towards the south. The Brazilian state of Amazonas benefits from the biggest intact share of the Brazilian part of the rainforest biome. This is no longer true for the neighbouring state Pará, which has apparently already lost its carbon retention capacity (Gatti *et al.*, 2021). Deforestation easily leads to immediate alteration of physical and chemical soil quality, generally resulting in more depleted, less permeable and highly erosion-sensitive soils (Fearnside, 2005; Laurance *et al.*, 2013; Tolimir *et al.*, 2020). Deforestation in low latitudes triggers atmospheric warming with specific risks for the Amazon rainforest biome (IPCC, 2021; Longobardi *et al.*, 2016). This biome is one of two global terrestrial biospheric tipping elements (IPCC, 2021; Lenton *et al.*, 2008).

Deforestation also leads to rapid negative change in soil microbial communities (Kroeger *et al.*, 2018) and soil physical properties (especially soil density, permeability), altering the greenhouse gas exchange between soil, plants and the atmosphere (Medina *et al.*, 1980; van der Werf *et al.*, 2009). Reducing deforestation and forest degradation is considered a cost-effective means to mitigate anthropogenic greenhouse-gas emissions (Gullison *et al.*, 2007; van der Werf *et al.*, 2009). Within the Brazilian Amazon rainforest biome, however, original forest is replaced by pastureland, agriculture (plantations), agroforestry and to a minor degree by aquaculture and mining activities – mostly since 1970 with establishment of the Transamazônica Highway (Fearnside, 2005; Moran, 1981). Regional soil degradation as a consequence of improper land-use management has been known for a long time (Nobre *et al.*, 2016; Sioli, 1983).

To what extent may such post-forest landcover types be sustainable – and how can this be assessed objectively? We targeted 13 locations across Amazonas state, accessing both forest and post-forest areas at each location to study deforestation effects in respect to land-use change (***Figure 1***). At each site, we repeatedly determined the soil chemical status and soil gas exchange (CO_2 CH_4, N_2O). Composite litter material (ORG) and mineral soil samples from two depths (TOP, BOT) were taken to quantify the element pools of macro and micronutrients as well as of carbon (C_t, C_{org}). Gas exchange serves as gauging biological vitality. All sampling took place in two subsequent rainy and dry seasons each from 2016 to 2017 (Matschullat *et al.*, 2020, and references therein).

Here, we test the hypotheses that

- Amazonas soils are truly nutrient and carbon depleted,
- Forest soils are less depleted than post-forest soils,
- Gas exchange distinctively differs between forest and post-forest soils,
- Agroforestry appears to be the best-adapted type of post-forest land cover,
- Sustainable alternatives to current land-use practices in the Amazon basin biome are possible.

Based on the evidence obtained from various physical science studies, an analysis of socioeconomic and socio-psychological boundary conditions finally helps to understand why the pathway to more resilient and sustainable land use appears challenging and how obvious obstacles could possibly be overcome on a medium term. Based on several thousand years of indigenous cultures, the Amazon basin today is dominated by settlers with mostly European roots from the south and the northeast of Brazil, where cattle herding is a key cultural characteristic. Changing habits is a most demanding, yet necessary challenge (Kibler *et al.*, 2018; Nepstad *et al.*, 2014).

Materials and methods

Within Amazonas state, we selected 13 upland (*terra firme*) locations, aiming at maximum diversity within the basin. Year-round accessibility by 4WD vehicles was mandatory, since other means of transport are either too time-consuming (boat) or too costly (aircraft, helicopter). The selected locations cover an area of roughly 170,000 km², generally with at least one forest site and a nearby post-forest site (***Figure 1*** and supplementary data). Post-forest sites are classified as pastureland (n = 3), agroforestry (Brazil nut trees: *Bertholletia excelsa*, rubber trees: *Hevea brasiliensis, açaí* palms: *Euterpe oleracea*, eucalyptus trees: *Eucalyptus* sp.; n = 4), and agriculture (corn: *Zea mays*, cassava: *Manihot esculenta*, orange trees: *Citrus sinensis*; n = 4). We grouped orange plantations (n = 2) under agriculture, justified by the fact that the orange trees were short (maximum height 2.5 m) and lacking other crops under the canopy. To classify the orange plantation under agriculture is somewhat arbitrary, yet does not radically change results to the alternative of agroforestry.

Each site had a minimum size of roughly 1 hectare (10,000 m²) and was visited at least three times in subsequent rainy and dry seasons from February 2016 to March 2017. Three sampling spots were selected on each site to represent site-specific variability. Very good data agreement between the sampling spots of any one site (gas exchange) and between seasons (soil chemistry) confirmed this selection. For more information on geological setting and site details, see Matschullat *et al.* (2020).

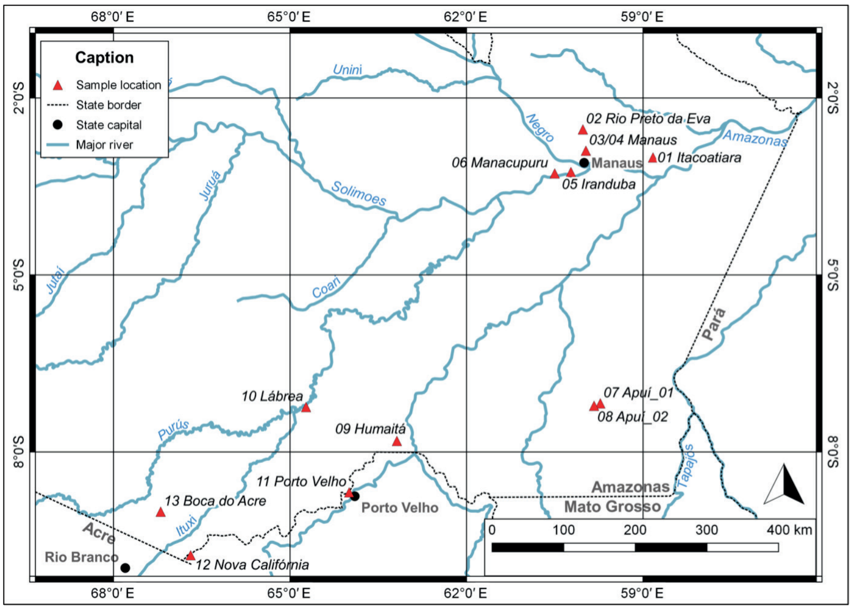

Figure 1: Position of the 13 sampling locations in the state of Amazonas, Brazil. See text for details.

A total of 159 composite mineral soil samples were taken from three spots per hectare by soil augers (Sondaterra, Piracicaba, Brazil) from 0–20 cm (TOP, n = 79) and from 30–50 cm (BOT, n = 80) depth. Sample weight was between 2 and 3 kg each. Samples were stored in gas and water-tight Rilsan® bags (Tub-Ex, Denmark) until further laboratory work. The intermediate 10 cm (20–30 cm) were discarded in order to minimise cross contamination between the two depth layers. The litter layer (various humus forms = ORG) was sampled as composites, too, with a volume of 2–3 liters each (n = 75). ORG samples were taken in cotton bags and left to air dry as of sampling. In parallel to sampling, soil water content (SWC) was determined by multiple TDR probe measurements around the drill spots. Soil water pH (H_2O) and electrical conductivity (both WTW instruments with Meinsberg electrodes, Germany) were determined in the laboratory on all composite samples. Field duplicates and certified standards (ORIS, BHA-1) as well as in-house reference (BraSol) materials were added for quality control.

Table 1: Detection limits (3 σ) for the methods used, individual elements and related concentration units.*

Method	- EA -			- WD-XRF -						
Unit	- wt-% -			- mg kg^{-1} -						
Element	C_t	C_{org}	N	Na_2O	MgO	SiO_2	P_2O_5	SO_3	K_2O	CaO
Value	0.04	0.03	0.004	60	60	50	5	10	5	20
Method	- WD-XRF -		- ICP-OES -						AAS	ICP-QMS
Unit	- mg kg^{-1} -		- mg kg^{-1} -						- mg kg^{-1} -	
Element	Mn_3O_4	Fe_2O_3	Mg	K	Na	Ca	Fe	Mn	Cl	Mo
Value	10	25	5	140	40	15	10	0.3	10	0.1

**EA: elemental analysis; WD-XRF: wavelength-dispersive X-ray fluorescence spectrometry; ICP-OES: inductively-coupled plasma – optical emission spectrometry; AAS: atomic absorption spectrometry; ICP-QMS: Inductively-coupled plasma - quadrupole mass spectrometry*

Samples were analysed in our Freiberg laboratories by WD-XRF (Bruker S8, Germany) for major, minor and a few trace elements, by ICP-OES (Perkin Elmer 3300 DV, USA) mainly for alkali elements and alkaline earths, by ICP-QMS (Perkin Elmer Sciex Elan 9000, USA) for trace and ultra-trace elements and by elemental analysis for carbon (total and organic), nitrogen and sulfur (Elementar Vario El Cube, Germany). The chlorine (Cl) analyses were performed by Mauana Schneider by AAS in Florianópolis, Santa Catarina, Brazil. For this work, macro (nitrogen, N; magnesium, Mg, phosphorous, P; sulfur, S; potassium, K; calcium, Ca) and trace nutrients (boron, B; chlorine, Cl; manganese, Mn; iron, Fe; nickel, Ni; copper, Cu; zinc, Zn; molybdenum, Mo) were quantified, as well as components such as carbon (C_t and C_{org}), and additionally sodium (Na) and silicon (Si), albeit non-essential for most plants, and cobalt (Co), which is considered potentially essential. Our determination limit was too high (2.5 mg kg^{-1}) to quantify selenium (Se); our detection limits for all elements are provided in ***Table 1***. For more details on analytical methods and quality control, see Matschullat *et al.* (2020).

Soil respiration was determined with the portable manual closed dynamic chamber system SEMACH-FG (Zurba, 2016). Each unit contained a Vaisala GMP-343 IR-spectrometer for fast and precise in-situ CO_2 determination, and sensors to determine soil and air temperature and humidity, air pressure and photosynthetically active radiation (PAR). With every campaign, the chambers were positioned on each of the three measurement spots per site onto soil-inserted rubber-sealed PVC rings ($ø_i$ 25 cm). Carbon dioxide concentrations were measured in situ over about 30 minutes per sequence, and repeated three times. With each third sequence, gas samples were additionally taken via a chamber interface to determine CH_4 and N_2O concentrations in the laboratory by gas chromatography (861 OC, SRI instruments Europe). These samples were taken with 20 mL syringes (0.25 µm needles) and filled into 12 mL double-wadded, pre-evacuated Exetainers® (type 839W, Labco, England). Gas fluxes were calculated from the field data and from those gas samples (at 0, 5, 10, 15, 20, 25, 30 minutes).

All sites were ortho-photographed by drone (DJI Phantom 3 professional). The high-resolution images were used to enhance satellite images from 1990 onwards (improvement of pixel information and more precise landcover data). Keen observations and non-structured interviews with land-owners, representatives of lobby-groups and governmental institutions as well as scientists with experience in Amazonas form a fruitful base of socio-economic and socio-psychological assessment, as Matschullat and Deschamps (2015) have shown for a case study in Minas Gerais, Brazil.

Results and discussion

To answer the key question of this work, we first characterise Amazonas soils (pedogeochemical and some physical characteristics), then assess soil gas exchange – both in direct comparison between forested and post-forest soils – and interpret the information in respect to the key question. Finally, we explore the obstacles and

Table 2: Median (n = 159) soil temperature (°C), humidity (SWC%), pH_{H2O}, electrical conductivity (EC, µS cm^{-1}), and granulometry (clay, silt, sand fraction, %; n = 56) – in Amazonas lowland (terra firme) soils (this work).

Parameter	TOP_{avg}	BOT_{avg}	TOP_{rs}	BOT_{rs}	TOP_{ds}	BOT_{ds}	TOP_{For-rs}	TOP_{For-ds}	TOP_{PF-rs}	TOP_{PF-ds}
Temperature	26.3	n/a	26.5	n/a	26.0	n/a	25.7	25.5	27.6	27.1
Soil water	27	n/a	33	n/a	12	n/a	27	11	37	12.5
pH_{H2O}	4.6	4.5	4.8	4.5	4.2	4.4	4.5	4.1	5.0	4.6
Electr. Cond.	46	27	33	23	66	30	45	79	28	46
Clay fraction	31.8	45.5	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Silt fraction	29.8	21.8	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Sand fraction	22.8	19.3	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

avg: average. rs: rainy season. ds: dry season. For-rs: Forest, rainy season. For-ds: Forest, dry season. PF-rs: Post-forest, rainy season. PF-ds: Post-forest, dry season pitfalls to more sustainable land use in the Amazon biome, expanding the view from the geosciences to a broader socioeconomic perspective.

Soil characteristics

Soils of the inner humid tropics differ in many respects from temperate soils due to their age and climatic boundary conditions. Yet, the basic processes and core properties remain the same – namely acidic, low electrical conductivity conditions and a low pool of mineral nutrients (Juo & Franzluebbers, 2003; Sanchez, 2019; ***Tables 2 and 3***).

Table 2 shows these characteristics, averaged for the locations and sites discussed here. From a mineralogical and granulometric perspective, the higher percentages of clay-size material in the BOT layer reflect clay particle transport to deeper soil horizons (argillation or lessivage; Buringh, 1970). Lower BOT electrical conductivities corroborate this result, reflecting higher sorption capacity of the deeper, more clay mineral-rich layers. Distinct differences between dry and wet seasons emerge, with considerably higher electrical conductivities in the dry season that result from less dilution by fresh rainwater. Soil solution pH is higher in the rainy season, independent of land cover. However, while TOP pH values are distinctively higher than in BOT during the rainy season, this signal reverses in the dry season, albeit less strongly. This likely reflect the solubility (non-solubility) of anionic complexes and thus respective soil water content (SWC).

Similarly, significant differences appear between forest and post-forest landcover. While TOP soil temperatures show a minor signal of seasonal dynamics under forest canopy, this difference is more pronounced and shows at least 2 °C higher temperatures on post-forest sites as result of reduced shading and lower evapotranspiration rates. Soil water content, while much higher in the rainy season, is higher in post-forest soils. This can be explained by rapid loss of soil porosity and surface compaction with and after deforestation, forcing water to stay longer at the surface of post-forest sites. Soil solution pH values are higher in post-forest soils (+0.5 units), likely reflecting the interrupted (broken) rapid recycling process between forest plants and soil, where plants (namely trees) rapidly take up nutrients, including buffering base cations, and is possibly also due to individual liming (***Table 3***). These effects are corroborated by much higher electrical conductivities in forest soil solutions as compared to those of post-forest soils.

Table 3: Nutrient element concentrations [mg kg^{-1}] in Amazonas soils (median values and ranges in ORG, TOP and BOT) in comparison with average upper continental crust (UCC), world soil average (WSA*), and European data (FOREGS*). Data rounded for clarity. *See below for references.*

Element	Layer	Median	Minimum	Maximum	ORG/TOP	UCC	WSA	FOREGS
C_t	ORG	422000	273000	496000	22	n/a	n/a	n/a
	TOP	19100	10200	32900				
	BOT	10000	4500	15400				
C_{org}	ORG	376000	270000	463000	24	n/a	n/a	n/a
	TOP	16000	7600	27400				17300
	BOT	8200	3400	12100				4000
N	ORG	14700	5400	23800	10	n/a	n/a	n/a
	TOP	1500	90	2300		n/a	n/a	n/a
	BOT	900	450	1150				
Na	ORG	80	10	3040	0.2	n/a	n/a	n/a
	TOP	420	120	3190		24260	10000	5940
	BOT	330	150	3340				6680
Mg	ORG	2010	190	3740	3.5	n/a	n/a	n/a
	TOP	570	40	1990		14950	9000	4640
	BOT	520	20	2350				5910
Si	ORG	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	TOP	309890	138350	413180		311380	280000	316430
	BOT	284180	138350	402900				317830
P	ORG	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	TOP	205	90	1700		650	750	570
	BOT	190	80	2030				440
S	ORG	1720	890	2760	6.4	n/a	n/a	n/a
	TOP	270	120	510		620	800	230
	BOT	210	80	540				110
Cl	ORG	3300	1900	22900	5.3	n/a	n/a	n/a
	TOP	620	90	29200		370	300	
	BOT	2360	290	10900				
K	ORG	1380	315	17050	2.6	n/a	n/a	n/a
	TOP	540	110	11450		23240	14000	15940
	BOT	480	100	11970				16770
Ca	ORG	6170	450	28800	34	n/a	n/a	n/a
	TOP	180	100	2150		25660	14000	6580
	BOT	150	90	860				8080
Mn	ORG	240	32	1390	2.6	n/a	n/a	n/a
	TOP	94	20	1130		77	530	503
	BOT	95	24	1340				465
Fe	ORG	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	TOP	26650	15810	162260		39180	35000	24550
	BOT	30280	16930	167160				26230
Co	ORG	0.26	0.03	2.6	0.3	n/a	n/a	n/a
	TOP	0.92	0.30	12		17.3	10	7.8
	BOT	1.3	0.34	13				8.0
Ni	ORG	2.0	0.24	15	0.4	n/a	n/a	n/a
	TOP	5.0	1.5	28		47	20	18
	BOT	6.5	2.3	32				22
Zn	ORG	25	11	150	1.2	n/a	n/a	n/a
	TOP	21	10	130		67	70	52
	BOT	26	12	144				47
Cu	ORG	8.9	3.8	32	1.0	n/a	n/a	n/a
	TOP	9.2	1.2	44		28	25	13
	BOT	9.7	4.2	43				14
Mo	ORG	0.22	0.03	5.2	0.1	n/a	n/a	n/a
	TOP	1.7	0.44	4.3		1.1	1.2	0.6
	BOT	1.7	0.30	5.7				0.5

n/a: not available. UCC: Rudnick and Gao (2014); WSA: Koljonen (1992); FOREGS: Salminen et al. (2004)

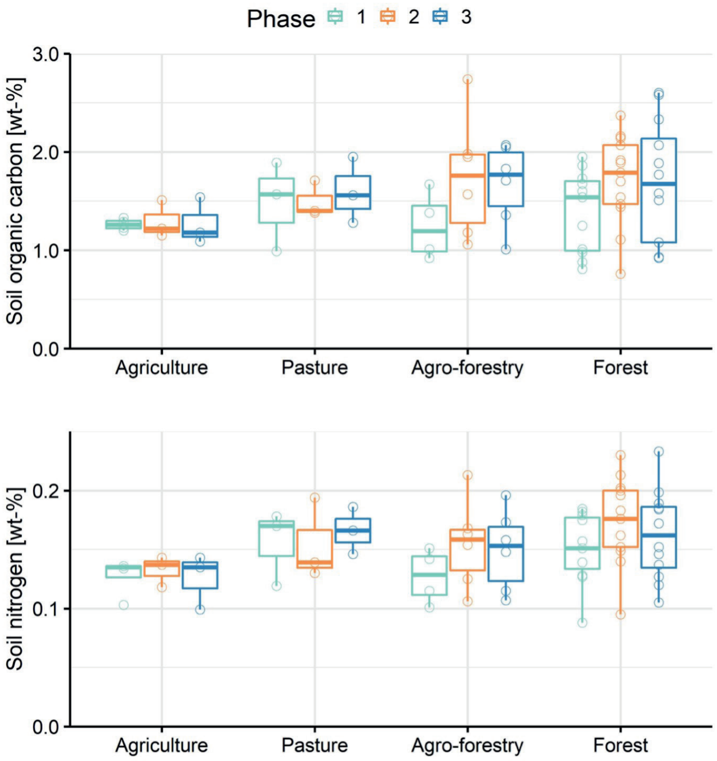

Figure 2: Organic carbon (top) and nitrogen (bottom) in lowland terra firme Amazonas topsoil – comparison between forest and post-forest grouped by land-use types. Phases 1 and 3: Wet seasons, phase 2: Dry season.

Macro and trace nutrient elements. Healthy plant growth demands availability of chemical elements, differentiated by macro (N, Mg, P, S, K, and Ca) and trace nutrients (B, Cl, Mn, Fe, Ni, Cu, Zn, and Mo), as well as components such as hydrogen, H; carbon, C; and oxygen, O. Compared to upper crustal averages (Rudnick & Gao, 2014) and world soil averages (Koljonen, 1992), most of these 14 determined elements are depleted in Amazonas mineral soil (***Table 3***). This is not true however, for C_t and C_{org}, N, Si, Cl, Mn, Fe, and Mo. Seasonal differences in physicochemical parameters (***Table 2***) are not reflected statistically in the pedogeochemical data, likely because the observation period as well as the time passed since deforestation (from months to a maximum of 60 years) is insufficient to show such change beyond doubt – except for carbon and nitrogen, where distinct differences develop rapidly with deforestation (***Figure 2***).

Interseasonal variability is noticeable for both C_{org} and N in topsoil and is most pronounced in forest and agroforestry land use. Organic C is highest in forest and agroforestry, while nitrogen shows the highest values in forest topsoil, yet there is no statistically relevant difference to agroforestry and pastureland (***Figure 2***). Comparing all median forest soil data with those of post-forest soils shows subtle yet clear differences in both TOP and BOT soil layers, however (***Table 4***, and Matschullat *et al.*, 2020: Tables 2 and 4). In both layers, Na, Mg, Si, P, K, Ca, Mn, and Fe show higher concentrations in post-forest soils, with strongest signals for Mg, K, and Ca, while carbon (C_t and C_{org}), nitrogen and sulfur show lower values in post-forest soils in the TOP layer; no difference is found in the deeper BOT layer. Those higher concentrations in post-forest soils are likely to be explained by soil management (fertilisation).

Carbon, including C_{org}, and N show similar average concentrations in lowland Amazonas mineral soils as the average of the European continent (Salminen *et al.*, 2004). Such unexpectedly high C and N concentrations were published much earlier, by Sanchez and Buol (1975) and references therein. The reason likely lies in the very fast biogeochemical recycling of organic matter in the inner humid tropics, with permanent C and N replenishment in forest soils by their plant cover. ***Table 3*** presents their very high values in biomass, here reflected by litter material (ORG). Truly depleted in the organic matter are Na, Co, Ni, and Mo, while C, N, Mg, S, Cl, K, Ca, and Mn are comparatively enriched. The depletion relates to both relatively high solubilities in the chemical weathering cycle (alkali and alkaline earth elements, P and S) as well as enhanced mobilities under highly acidic conditions (Co, Ni, Cu and Zn). The relative mineral soil enrichment of Cl and Mo may relate to lithology (soil mineralogy), to plant physiological activity (Mo: Gardner *et al.*, 2014) and to soil biological (fungal) activity, typical for the humid tropics (Cl: Bastviken *et al.*, 2007; Svensson *et al.*, 2017).

Total and organic carbon significantly decrease from forest to post-forest soils in both TOP and BOT layers (***Figure 2***). The same is noticeable, albeit less pronounced, for nitrogen, sulfur and chlorine. Halogenides can be liberated with degradation of organic matter into soils (Keppler *et al.*, 2003; Svensson *et al.*, 2021). Carbon, N, S and Cl are closely related to microbial, particularly fungal, metabolism, which becomes suppressed with the transition from more or less undisturbed forest to post-forest ecosystems. Sodium, Mg, Si, P, K, Ca, Fe, Co, Ni, Zn, Cu and Mo show higher concentrations in the post-forest TOP soil material, and only Na, Mg, P, K, Fe, Co, Ni, Zn, and Co also in the post-forest BOT layers as compared to the forest soils. We attribute this to reflecting the strongly decreased soil-plant interface, where plants (mostly trees) no longer take up and store these elements in their biomass; it remains in the soil instead.

Soil gas exchange

Within a certain range of boundary conditions (soil pH, temperature and water content), soil gas exchange is relatively high in the inner humid tropics as compared to other climate zones; this is true independent of land-use type. Within the tropics (and elsewhere), wetlands tend to show the highest respiration rates (CO_2 equivalents), followed by forested land, grassland, cropland and finally barren land (Oertel *et al.*, 2016).

We observed distinct gas exchange differences between wet and dry seasons for CO_2, CH_4 and N_2O, as well as for land cover (forest versus post-forest), (***Figure 3***). Forest soils show generally higher CO_2 and N_2O release and higher CH_4 uptake rates than post-forest soils, with distinctively lower signals for each gas species in the dry season.

Forest soils showed the highest median CO_2 emissions (in µmol m^{-2} s^{-1}) with 5.46, followed by almost equal values for agriculture (3.38), pasture (3.32) and agroforestry (3.30). The same sequence was found for median N_2O values (in µmol m^{-2} h^{-1}) with forests showing 0.90, followed by agricul-

Table 4: Comparison of median (nutrient) major, minor [wt-%] and trace elements [mg kg^{-1}] values between forest and post-forest soils in the mineral soil layers TOP and BOT soils in Amazonas (this work).

Element	Layer	Forest	Post-forest	Ratio*
C_t wt-%	TOP	2.15	1.73	1.24
	BOT	1.00	0.92	1.09
C_{org} wt-%	TOP	1.69	1.44	1.17
	BOT	0.83	0.76	1.09
N wt-%	TOP	0.148	0.141	1.05
	BOT	0.083	0.084	0.99
Na wt-%	TOP	0.036	0.047	0.78
	BOT	0.036	0.054	0.67
Mg wt-%	TOP	0.052	0.079	0.66
	BOT	0.048	0.093	0.52
Si wt-%	TOP	30.9	31.7	0.97
	BOT	28.4	28.6	0.99
P wt-%	TOP	0.017	0.022	0.80
	BOT	0.013	0.019	0.68
S wt-%	TOP	0.027	0.024	1.13
	BOT	0.021	0.020	1.05
K wt-%	TOP	0.036	0.163	0.22
	BOT	0.035	0.273	0.13
Ca wt-%	TOP	0.016	0.036	0.44
	BOT	0.014	0.016	0.87
Mn wt-%	TOP	0.008	0.009	0.83
	BOT	0.008	0.008	0.91
Fe wt-%	TOP	2.45	2.73	0.90
	BOT	2.77	3.94	0.70
Cl mg kg^{-1}	TOP	720	520	1.38
	BOT	2480	2360	1.05
Co mg kg^{-1}	TOP	0.83	0.96	0.86
	BOT	1.1	1.4	0.79
Ni mg kg^{-1}	TOP	4.7	5.3	0.89
	BOT	5.7	7.7	0.74
Zn mg kg^{-1}	TOP	19.9	23.3	0.85
	BOT	24	29	0.83
Cu mg kg^{-1}	TOP	7.3	9.8	0.74
	BOT	7.5	11.1	0.68
Mo mg kg^{-1}	TOP	1.41	1.73	0.82
	BOT	1.70	1.68	1.01

**Minor numerical differences result from rounding the concentrations in the table*

ture (0.67), pasture (0.35), and agroforestry (0.28). Median values for CH_4 (in µmol m^{-2} h^{-1}) clearly show forests as a methane sink (-3.62), while agriculture (0.00) and agroforestry remained neutral (0.00) and only pastureland soils acted as source (1.25). The higher forest soil signals for CO_2 and N_2O certainly reflect higher soil microbial activity and root density as compared to those of post-forest soils. The sink quality of forest soils for CH_4 do corroborate this outcome. That the post-forest land-use types do not show major differences between themselves appears reasonable given the limited period of time that has passed since deforestation. While post-forest soil emissions directly escape into the atmosphere, forest soil emissions largely stay within the tree canopy – the net escape signal into the atmosphere is lower than that of post-forest soils (Pan *et al.*, 2011). Our laboratory CO_2 values (gas chromatography) were very consistent with those measured earlier in-situ (not shown).

When separating the central part of Amazonas state (Amazonas-Solimões River "valley") from the southern reaches of the basin (south of Transamazônica Highway near Rondônia and Acre states), relatively higher CO_2 (and N_2O, not shown) respiration signals emerge in the more humid central part. However, the central region appears to be a larger CH_4 sink than the south (see ***Figure 3***). This behaviour likely reflects more constant rainfall in the central part, even in the dry season – with related optimal water availability – as compared to the extreme drought experienced in September 2016. This argument is corroborated by the gas exchange behaviour in the three subsequent campaigns and a flux optimum between 20 and 40% SWC.

Obviously, forest soils represent more balanced and more resilient conditions compared to any post-forest land use. In topsoil, particularly carbon (C_t and C_{org}) is higher, and gas exchange shows the highest vitality in forest soil. While no significant differences emerged between agriculture and agroforestry in our study, pastureland clearly qualified as the worst possible post-forest land use, conforming findings of Bringhurst and Jordan (2015) and of Reiners *et al.* (1994).

Land-use alternatives

Decision makers often pursue and seek to encounter and apply a single ultimate solution for a complex issue. However, reality and scientific theory teach us that there are no simple or single-track solutions for complex problems, since many such problems are rather wicked and escape quick "fixes" (Ostrom *et al.*, 2007; Rayner & Malone 1998). The issue of sustainable land-use management in the Amazon basin certainly belongs into this category. While simple solutions appear attractive, they may do more harm and damage than doing nothing. We therefore propose a different approach in form of a conceptual model that integrates project and external experience with long-term experience by Embrapa (the Brazilian Agricultural Research Corporation).

The Amazon biome and its socioeconomic challenges are a highly complex meta-system, not even fully understood by natural and social sciences. Overprinting this biome and its functionality with any kind of post-forest land use increases complexity in close spatial proximity to the original forest system. The various stages of biophysical immaturity of human demand-driven land cover develops its own dynamics. Small-scale slash-and-burn practices with rotating small-scale agriculture, such as practiced by indigenous people, have little more disturbing effect than a natural forest opening triggered by the loss of some large mature trees, e.g., felled by a tropical wind storm. Individual small-scale farming, independent of the type of plantation, is likely also of limited disturbance. Yet, collectively, many individual small-scale farms in close proximity to each other may rapidly magnify into a much larger-scale disturbance. In consequence, the biome

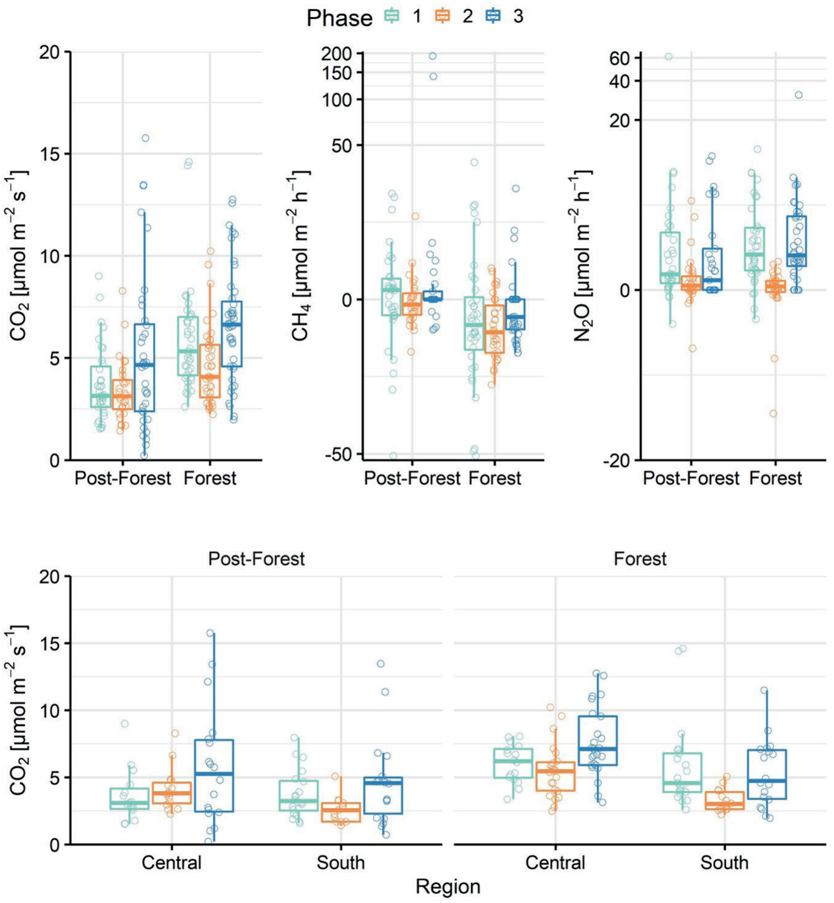

Figure 3: (Top) CO_2, CH_4 and N_2O gas exchange at post-forest and forest sites. (Bottom) CO_2 exchange, differentiated by the central and southern parts of the Amazon basin. Both Amazonas lowland (terra firme) soils. Phase 1 and 3: Wet seasons; phase 2: Dry season. Note the different scales (y-axes).

becomes fragmented, comparable to the effects of large-scale industrial agriculture. ***Figure 4*** shows land degradation in five-year increments from 1990 to 2015 near Boca do Acre (location 13 in ***Figure 1***). Numerous small farmers rapidly transformed the original forest to dominantly pastureland and are now facing water scarcity and soil fertility decrease, since creeks are drying up and the remaining forest patches no longer supply enough water via water retention. Since 2017, Embrapa has been assisting individual farmers to re-establish “forest areas” at least alongside former creeks and valleys, aiming at re-establishing a minimum supply of water for cattle and people.

Forest is the natural land cover for the Amazon biome. If humans with their current land-management practices retreated from the land, woodland would re-establish almost everywhere within years or decades. Such re-establishment would not be equal to a full recovery of the ecosystem, since the system would show its former disturbance for centuries. This is visible, in the biosphere reserve Adolfo Ducke near Manaus (location 04; ***Figure 1***), where about 100 years after deforestation, the now protected system still shows impacts from the past (Oliveira *et al.*, 2011). Recognising the relevance and importance of the natural Amazon rainforest biome for Brazil and beyond, and the doubtlessly detrimental effect of non-sustainable land use in the basin, society needs to think about ways out of this vicious cycle of a seemingly inescapable drive for more land grabbing for agriculture, agroforestry, settlements and industry, mining and other forms of natural resource exploitation (Brando *et al.*, 2013).

Opposite to the example near Boca do Acre (location 13, ***Figure 4***), an earlier devastated farm with pastureland near Itacoatiara (location 01; ***Figure 1***) started to radically re-establish more natural land-use around 1990. The satellite images demonstrate that over the past 30 years, most of the formerly devastated soils have recovered under the canopy of newly planted Brazil nut trees with agroforestry economy (***Figure 5***), showing that carefully managed agroforestry may have significant beneficial effects.

Today, about 34 million people live in the Amazon basin. The population in the state of Amazonas state reached 4.207 million in 2020, with more than 2.2 million in the capital Manaus (IBGE 2021). Yet, this is very recent growth. Manaus had less than 300,000 inhabitants in 1980. Villages and towns that were home then to a few hundred to a few thousand residents are today (2020) home to tens of thousands. This also applies to the population dynamics of places near our sampling and experimental locations (see ***Figure 1***) such as Itacoatiara (location 01, population 102,701), Rio Preto da Eva (location 02, 34,106), Apuí (locations 07 and 08, 22,359), Humaitá (location 09, 56,144), Lábrea (location 10, 46,882) and Boca do Acre (location 13, 34,635). Families established their lives and infrastructure has been developed. At present, hospitals, schools and even satellite campuses of universities, power plants, shopping centres, small airports and typical modern amenities can be found almost everywhere – not only in the state capitals.

Two key issues connected to this development appear underexplored. People with ethnic roots in Amazônia are a small minority today (data from governmental and NGO sources range between 80,000 and 200,000). Most people, even in more remote places, are immigrants from southern and north-eastern Brazil or from other countries. Most are still newcomers, since modern settlement started in the second half of the 20th century with the development of the Transamazônica Highway (Fearnside, 2005). Since immigrants came to develop the land and make a better life for themselves, a frontier spirit developed (similar to that in North America in the 19th century) with a clear emphasis on survival and economic success. Most of these people endured very tough conditions before they or their offspring reached a certain economic affluence, which can now be observed in many places. This affluence, however, came with the price of land degradation and massive deforestation in some places (***Figure 4***; Boca do Acre).

The people’s urge and need to survive and to succeed was coupled with rather reckless and ongoing suppression of indigenous people (first nations). With few exceptions, the radically different indigenous lifestyle has never been appreciated or even respected by most new immigrants. A perception of superiority over indigenous people has further hampered any attempt to learn from their long-term experience on how to deal with the harsh natural boundary conditions in the Amazon up to today.

In effect, new settlers mostly apply land management techniques that they imported from their home places. They force these techniques onto a radically different natu-

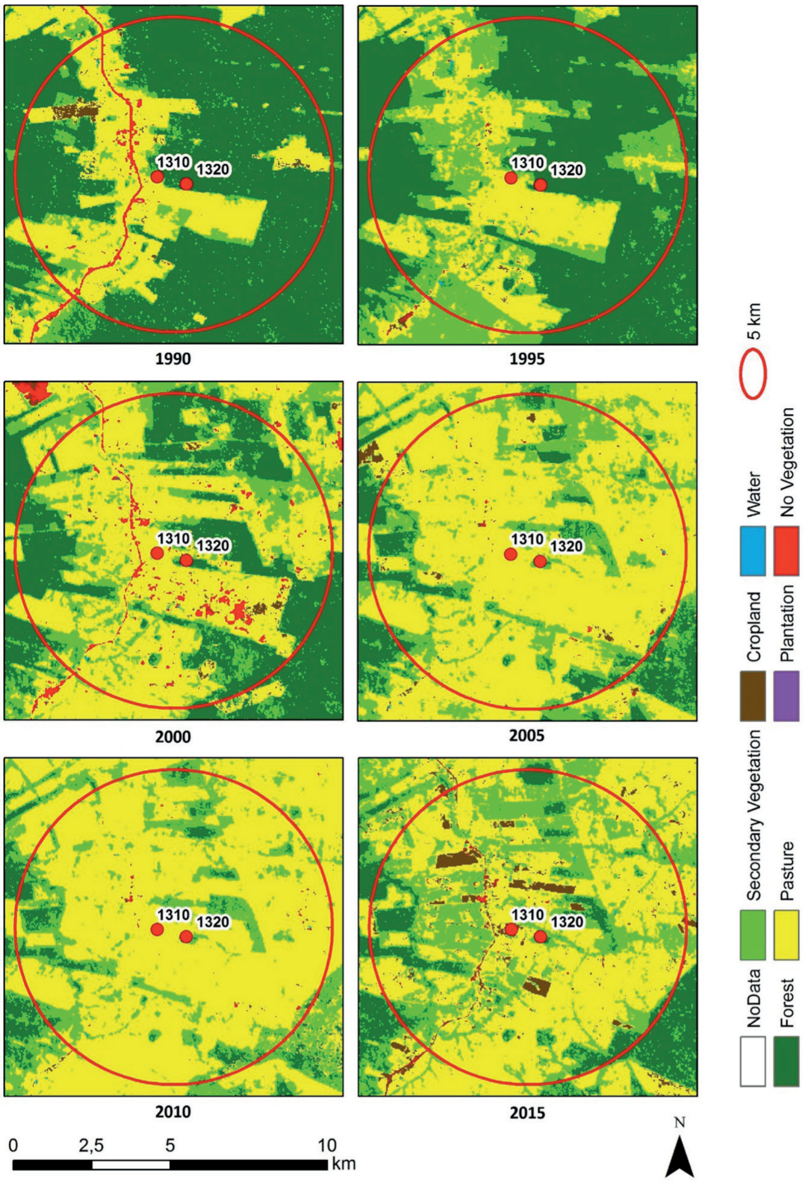

Figure 4: Land degradation dynamics near Boca do Acre (location 13) with time (1990–2015). The most prominent feature is the transition from forest (dark green) to pasture land (yellow).

ral environment that cannot deal with the related impacts. Agricultural land may deliver decent yields for a limited number of years before soils become exhausted, leading the agriculturist and farmer to deforest more area for plantations or pastureland. The ever-growing immigrant population propagates the need for more land with every generation, demanding more and better infrastructures – driving a vicious cycle of biome disintegration and decay.

Brazilian and international scientists have produced a wide range of studies with robust data documenting the lack of social and environmental sustainability (Castro *et al.*, 2019; Freitas & Freitas, 2018; Nobre *et al.*, 2016; Pereira *et al.*, 2019; Stewart *et al.*, 2021) as well as the global risk of the ongoing hegemonic development path in the Amazon (Bastos Lima *et al.*, 2020; Pereira & Viola, 2020). Such a path is characterised by the reduction of social and natural complexity in the Amazon region to an asset to be transformed into economic values in which the land is mostly owned by stakeholders outside of the Amazon region (Castro, 2019; Freitas & Freitas, 2018; Monteiro, 2005; Stewart *et al.*, 2021; Urzedo & Chatterjee, 2021).

Changing this structure is no easy task and exceeds the competence and responsibility of science. It is the political system that has to organise decision-making processes leading to choices with broad social acceptance. Science-based observations of the way the political system operates in Brazil and in the Amazon states and municipalities can identify the structures that maintain the status quo and the obstacles to alternative development paths. The development agenda is mostly defined by players who see biological and geological diversity of the natural environment as a commodity only, able to be transformed into economic value (Abel, 2021; Aumeri and Bampi, 2019; Fearnside and De Alencastro Graça, 2006; Freitas & Freitas, 2018; Silva & Sobreiro, 2018; Urzedo & Chatterjee, 2021). That vision is highly appreciated and supported by the central government, which considers the Amazon as an important asset to serve national development interests (Carvalho *et al.*, 2020; Oliveira Neto & Nogueira, 2020). Income generated by the export of mining, logging and agrarian products (meat, crops, etc.) contributes substantially to the national trade balance (Carvalho *et al.*, 2020; Martins & Rugitsky, 2018). The central government widely and directly encourages these activities by special credit-rates and tax-liberation, and indirectly by failing to monitor or punish environmental legislation violations and by legalisation of land grabbing (Castro, 2019; Cardoso Jr & Rey, 2019).

On the other hand, economic actors who invest in sustainable forms of land and natural resource use receive next to no support from political authorities and may even face local resistance (Pokorny *et al.*, 2014; Santos *et al.*, 2021). Although economic viability and the success of more environmentally prudent forms of natural resource usage can be demonstrated, these still form a niche in the Amazonian economy (Gasperini & Gomes, 2020).

Dispute about the development path of a region is a political one, characterised by a battle of ideas and actors with different economic and political power (Lacerda, 2019; Moreira & Pereira, 2020; Sobrinho *et al.*, 2018). It is crucial that a scientific community committed to a project dealing with aspects of a future society alongside social and environmental sustainability take an active role in the political dispute. Such positioning becomes even more important when public discussion is increasingly characterised by fake news and a growing aversion to scientific explanations in favour of those that deny complexity (Biancovilli *et al.*, 2021; Figueira & Oliveira, 2017; Giordani *et al.*, 2021; Silva & Viera, 2021). In respect to the Amazon, global networks that back local researchers and enable the exchange of experience with other regions of the humid tropics are most helpful. In doing so, universities – as a fundamental element of the scientific system – can

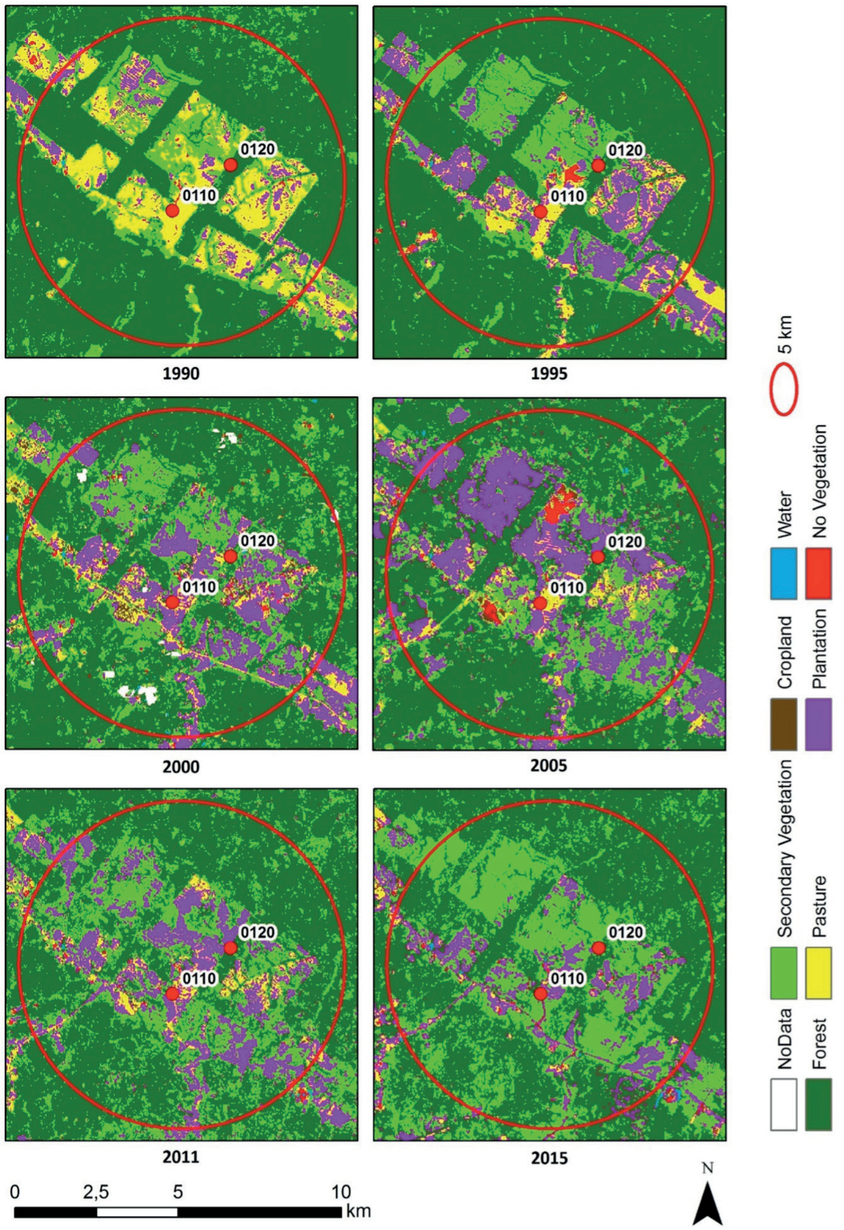

Figure 5: Land (and soil) recovery by transition from devastated pastureland (1990) to dominantly agroforestry (2015) with Brazil nut plantation (Bertholletia excelsa Bonpl. in light green) near Itacoatiara (location 01).

assume a more proactive role as adviser or mediator in political decision-making processes regarding future choices of development paths of the region where they are socially and economically embedded (Mathis, 2001).

Approaches to problem-solving – Hypotheses

The following hypotheses are derived from numerous informal interviews with local people, mostly farm families.

- Some farmers do understand that their activities are non-sustainable;
- Such farmers do not want to degrade their land;
- Most farmers have no knowledge on how to change their practices without compromising their economic survival;
- The younger generation, often with some higher educational background, mostly wishes to stay in the region;
- This generation seeks answers to the described issues and wants to find solutions;
- There is critical mass in the current "immigrant" population that wishes to live and produce more sustainably;
- Solutions or more precisely, distinct improvements towards more sustainable land use without compromising peoples' right to live and prosper, can be found on a local level only;
- Many if not most people in the region feel neglected by politicians and decision-makers in the capitals;
- A spirit of "every man for himself" prevails.

If we accept the additional hypothesis that only forestland is appropriate and sustainable for Amazon basin boundary conditions, then the direction to be taken must be towards maximum preservation of this natural resource. If we likewise accept results of acknowledged scientific studies that large-scale conventional agriculture for cash crops (independent of whether it consists of very large single farms or very many much smaller ones) can lead to quick soil impoverishment (nutrient loss, compaction, etc.) and soil loss (erosion), then we must stop this development and establish much tighter and efficient control to prevent further increase in such non-sustainable land use.

Yet there are 34 million people who already live there, have a right to live there and have the natural human wish to prosper and to further develop their region. To this respect, the Amazônia challenge is no different from other global challenges that demand human behavioural change as a prerequisite to betterment. This understanding that the challenge is of major dimensions and will not and cannot be met by piecemeal approaches bears the key for finding pathways to solutions (***Figure 6***).

Seven Pathways to solutions

1. Allow for many and highly "individualised" solutions. Try all options that have not proven false or misleading already. No one single roadmap can fix the issues. Instead, numerous pathways could help reach the aim, since local conditions highly differ from place to place with respect to social, economic and natural conditions – the sustainability triad.
2. Open alternatives, think out of the box, use local potential – and include indigenous experience. Solutions, or more precisely distinct improvements towards more sustainable land use without compromising peoples' right to live and prosper can be found on a

local level only. Targeting individual farms and developing better land management techniques that make use of the potential without exhausting it is one of the necessary steps. Another step lies in fulfilling the demands of people without necessarily allowing for business-as-usual activities. Related alternatives can include very different, non-agriculture-related job opportunities or paying for the recovery of ecosystem services on a farm rather than for typical farm products (Börner *et al.*, 2010; Nicholaides *et al.*, 1985).

3. Stop business as usual and explore higher levels of the value chain. Since the Amazon biome is not suited for successful long-term intensive conventional agriculture (neither plant nor animal production), alternatives are needed besides small-scale sustainable agricultural practice. So far, the potential for the productive industrial sector has been radically underexplored, with Manaus being the only place with noticeable industrial production activities. Since industry, including mining, can be done with much smaller ecological footprints than agriculture (Bansal, 2005; Matschullat & Gutzmer, 2012; Owen & Kemp, 2013), it appears worthwhile to actively pursue specific and environmentally-benign industrial development. However, development without compromises in the qualities of air, water and soils as well as social issues does not emerge without commitment to functional and honest governmental institutions nor clear environmental assessment studies, must follow the highest standards and use the best available technologies. Such development could and would turn Amazonas into a radically different human environment.
4. Make serious and ambitious long-term plans and think from the end, not the start. Just as building the Transamazônica Highway was a serious challenge, involved national effort, and triggered a spirit comparable to sending the first humans to the Moon, similar effort and enthusiasm is required to manage the transition from current ways of non-sustainable life in the Amazon basin to a benign and yet beneficial for-the-people lifestyle. Such transition cannot be brought about overnight. Yet in the next 30 years, significant steps can be made that may halt the current rate of deforestation and degradation without forcing people away from the basin. Obviously, this calls for a concerted action plan and full support by the Federal Government and all its ministries as well as all state governments involved with their authorities. Such a master plan demands clear priority setting and perseverance.

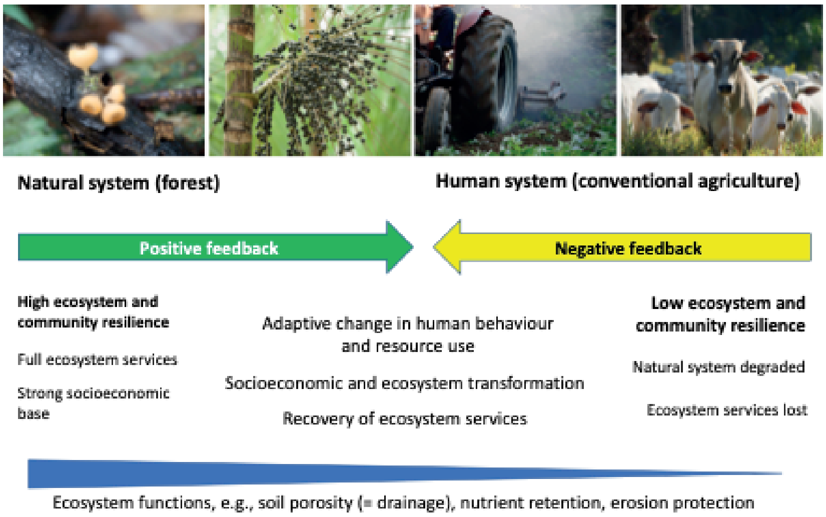
Natural system (forest)
Human system (conventional agriculture)
Positive feedback
Negative feedback
High ecosystem and community resilience
Full ecosystem services
Strong socioeconomic base
Adaptive change in human behaviour and resource use
Socioeconomic and ecosystem transformation
Recovery of ecosystem services
Low ecosystem and community resilience
Natural system degraded
Ecosystem services lost
Ecosystem functions, e.g., soil porosity (= drainage), nutrient retention, erosion protection

Figure 6: Pathway to a more sustainable future of the human–nature interface in the Amazon basin.

5. Appreciate local knowledge and experience, plan with the people, not above the people. They have to (and want to) live there and bear the consequences. Instead of any further (half-hearted) top-down-only attempt to mitigate deterioration of the Amazon biome and to develop sustainable adaptation to the environment, we suggest an accompanied bottom-up approach. People are suspicious of "politics" and politicians and are unlikely to collaborate if they feel that they are being forced to change by government.
6. Existing, albeit relatively weak stakeholders in the region, who are willing and capable of becoming active players in reaching the prescribed aim, should receive the capacity to work on those changes that their specific social and natural boundary conditions permit. Many examples of local community spirit exist, partly groups of immigrants from the same area or region (e.g., Northeasteners or Southerners). There are established bodies such as IDAM (Institute for Sustainable Agriculture and Forestry Development of the State of Amazonas) under the wings of Embrapa – and the highly respected Embrapa itself. Both Embrapa and IDAM are closely linked with local agriculturists and farmers, a promising base for developing platforms and movement for successful change at that end.
7. Transform existing institutions to provoke better collaboration, to decrease futile activism and to increase efficiency. Informal and creative education tools, such as those developed by FEAM (State Environmental Foundation) in Minas Gerais for village communities near mine sites (Oberdá *et al.,* 2011) can – if done with engaged and well-trained personnel – lead to rather rapid behavioural change, provided that realistic alternative options are being offered. Stakeholders must develop the necessary awareness and understanding for the issue. It is unrealistic to assume that any such positive change can take place without incentives and significant governmental investment. While this notion may appear to contradict any bottom-up approach, it does not: the allocation of funding and infrastructure must not equal dominance over decisions

on how money is spent and which kind of infrastructure is to be developed. It appears likely, however, that an existing body (such as IPAAM, Institute for Environmental Protection of Amazonas) or a newly created authority is needed to coordinate related efforts and to act as the interface between government with its authorities and the many local activities. Concerted long-term action demands concrete, concise and creative yet realistic planning, bolstering the public perception and appreciation of milestone achievements (Schönenberg *et al.*, 2015).

8. Make sure that all plans get scrutinised, and that independent capable experts critically evaluate all steps along the way. A coalition of state authorities with NGO's and citizen committees has the potential to trigger sustainable change, to entice people to adapt and to progress towards a much less detrimental future for the Amazon basin. Science cannot – and should not – drive this process. Science can and should monitor and analyse the changes, both from the human perspective (sociology, social psychology) and the natural perspective (ecosystem recovery and change). Do not worry about necessary course corrections along the way. People can – and should – drive this process and be encouraged and respected in their efforts. Amazonians do have the chance to find ways towards equilibrium between their Amazon biome and its needs and their own demands. Every successful step in that direction will entice others and make Amazonians proud of their achievement – an important driver of positive development. It is not too late at all and the benefit doubtlessly is extremely significant capital for Brazilian's future.

Conclusions

Persistence of any human system poses major challenges to those who intend to change that system – even if negative consequences of a specific established system may be apparent. This statement is likewise true for "modern" land use management in the inner humid tropics such as the Brazilian Amazon biome. If conventional practices reach their limits, then which sustainable land-use alternatives could emerge? To help elucidate that crucial question, we aimed at improved understanding of both the current chemical soil status and its gas exchange characteristics in direct comparison between little or undisturbed forest land as the natural land cover variant and various types of post-forest land-use.

- The first hypothesis that "Amazon soils are truly nutrient and carbon depleted" was rejected. The soils are not carbon (nor nitrogen depleted), and the same holds true for Si, Cl, Mn, Fe, and Mo. The other macro and micronutrients are clearly depleted. This can be explained through weathering processes and solute export as well as through fast recycling in the short circle between soils, plants and atmosphere.
- The second hypothesis that "Forest soils are less depleted than post-forest soils" was verified for a few elements only, namely carbon, nitrogen, sulphur and chlorine. The other analytes showed relative enrichment at least in the TOP layer, likely reflecting a shift in metabolic boundary conditions.
- The third hypothesis, "Gas exchange distinctively differs between forest and post-forest soils" was verified and corresponds to both reduced soil microbial activity as well as to decreased water storage capacity in post-forest soils. Forest soils are the most vital ones.
- The fourth hypothesis that "Agroforestry appears to be the best-adapted type of post-forest land cover" was verified. Pastureland is more damaging than other types of post-forest land cover.
- The fifth hypothesis "Sustainable alternatives to current land-use practices in the Amazon basin biome are possible" can be responded to on a theoretical level only, since current political and managerial land-use practice does not allow for practical evaluation.
- Sustainable management of the Amazon biome requires integrated analysis of the system as a socio-ecological system. Coupling human data (e.g., stakeholder sense of place) with ecological data (e.g., carbon and nutrient cycling, hydrological processes) can potentially isolate opportunities for restoration and building stakeholder attachment to a high-functioning ecosystem state.

Our data corroborate the many findings that the vulnerability of the biome is very high and critical large-scale forests need to be preserved to ensure long-term prosperity in the region. Science per se can deliver evidence and make meaningful suggestions to avoid or at least mitigate problems – it cannot implement societal change. Here, homo politicus is in demand to "make things happen".

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GEMAS: Geochemistry of European agricultural and grazing land soil

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The project Geochemical Mapping of Agricultural and grazing land Soil (GEMAS) was carried out in 33 European countries (5.6 million km^2) with an average sampling density of 1 site per 2500 km^2. The main objective was to assess the chemical quality of productive soils. All collected soil samples were prepared in the same laboratory, and subsequently analysed for the same suite of elements and physicochemical parameters in the same laboratory following a strict quality control procedure. Data interpretation revealed that few soil samples reach element concentrations where toxicity may become of concern. However, more than 10% of samples contain such low element concentrations that deficiency for optimum plant growth and animal health may be a much larger issue warranting attention.

Le projet Cartographie géochimique des sols agricoles et de pâturage (GEMAS - Geochemical Mapping of Agricultural and grazing land Soil) a été mené dans 33 pays européens (5,6 millions de km^2) avec une densité d'échantillonnage moyenne de 1 site pour 2500 km^2. L'objectif principal était d'évaluer la qualité chimique des sols productifs. Tous les échantillons de sol collectés ont été préparés dans le même laboratoire, puis analysés pour la même suite d'éléments et de paramètres physicochimiques dans le même laboratoire suivant une procédure de contrôle de qualité stricte. L'interprétation des données a révélé que peu d'échantillons de sol atteignent des concentrations d'éléments pour lesquels la toxicité serait préoccupante. A contrario, plus de 10 % des échantillons contiennent des concentrations d'éléments si faibles, que la déficience pour une croissance optimale des plantes et la santé animale forme un problème bien plus préoccupant qui mérite une attention particulière.

El proyecto Cartografía geoquímica de suelos agrícolas y de pastoreo (GEMAS) se llevó a cabo en 33 países europeos (5,6 millones de km^2) con una densidad de muestreo promedio de 1 sitio por 2500 km^2. El principal objetivo fue evaluar la calidad química de suelos productivos. Todas las muestras de suelo recolectadas se prepararon en el mismo laboratorio y, posteriormente, se analizaron para el mismo conjunto de elementos y parámetros fisicoquímicos en el mismo laboratorio siguiendo un estricto procedimiento de control de calidad. La interpretación de los datos reveló que pocas muestras de suelo alcanzan concentraciones de elementos donde la toxicidad puede convertirse en motivo de preocupación. Sin embargo, más del 10% de las muestras contienen concentraciones de elementos tan bajas que la deficiencia para el crecimiento óptimo de las plantas y la salud animal puede ser un problema mucho mayor que merece atención.

Introduction

With an ever growing world population efficient and superior quality food production is becoming a major challenge (FAO, 2019). Well-organised and safe agriculture and animal husbandry depend substantially on healthy soil. Plants and animals require sufficient amounts of major and minor nutrients and low concentrations (or availability) of potentially toxic elements in soil.

The project Geochemical Mapping of Agricultural and grazing land Soil (GEMAS) was carried out by the Geochemistry Expert Group of EuroGeoSurveys in cooperation with Eurometaux (Association Européenne des Métaux), and other European and international institutions (Reimann *et al.*, 2014a, 2014b). It documents, for the first time, the concentration of almost 60 chemical elements, analysed by three different methods (total, aqua regia and cold leach concentrations) and physicochemical parameters determining nutrient availability and binding in agricultural and grazing land soil samples at the scale of the European continent (33 countries and 5.6 million km^2 were covered). In total, 2108 samples were collected from regularly ploughed fields (***Fig. 1a***), and 2024 samples from land under permanent grass cover (***Fig. 1b***). The agricultural soil samples were collected from the Ap horizon, the layer that has been disturbed by human activity such as mixing of the upper soil by ploughing in agricultural landscapes. In this case, the 'p' refers to the 'ploughing depth', which is on average down to a depth of 20 cm. The graz-

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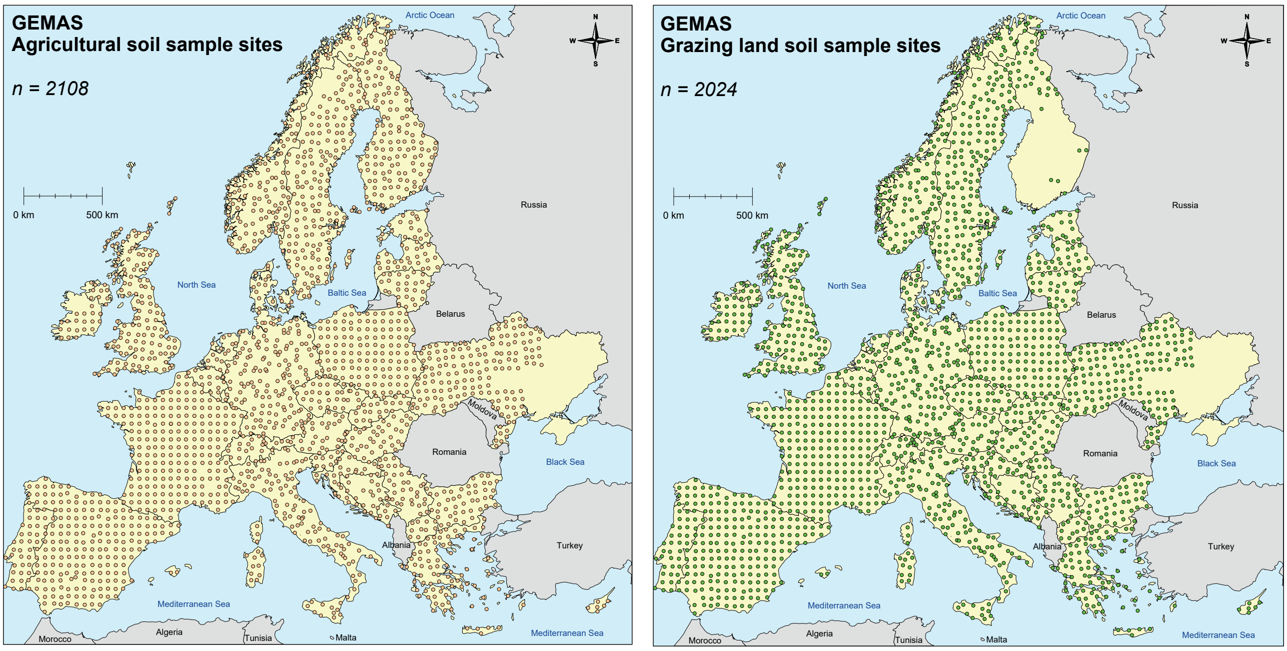


Figure 1: Maps showing the distribution of (a) agricultural soil samples, and (b) grazing land soil samples. A few countries collected samples at the grid nodes of a regular grid of 50 × 50 km, and other countries used a random sampling scheme within the same grid dimensions, and both retained the nominal sampling density of 1 site/2500 km^2.

ing land soil samples were collected from land under permanent grass cover or land that has not been disturbed for a period of at least ten years. As the interest is in the grass on which the animals graze, the upper 10 cm of soil was sampled as grass roots are usually concentrated in this section.

The samples were collected according to the specifications of the European Union's REACH regulation (Registration, Evaluation, Authorisation and Restriction of Chemicals; EC, 2006; EGS-GWG, 2008; Reimann, 2014). The REACH regulation aims to improve the protection of human health and the environment from potential risks posed by chemicals.

The GEMAS project data sets were made available to the general public in 2014 with the release of a two-volume atlas with the title *"Chemistry of Europe's Agricultural Soils"* (Reimann *et al.*, 2014a, 2014b).

As part of GEMAS valorisation, a series of peer-reviewed publications, where detailed interpretation of the continental-scale distribution of single elements or related groups of elements, have been published, e.g., Reimann *et al.* (2012a – Pb); Ottesen *et al.* (2013 – Hg); Tarvainen *et al.* (2013, 2014 – As); Scheib *et al.* (2012 – Nb); Sadeghi *et al.* (2013 – Ce, La, Y); Baritz *et al.* (2014 – C); Birke *et al.* (2014a, 2016, 2017 – Cd); Poňavič and Scheib (2014 – Se); Cichella *et al.* (2014 – U, Th, K); Ladenberger *et al.* (2015 – In); Albanese *et al.* (2015 – Cr, Ni, Co, Cu); Négrel *et al.* (2016 – Ge; 2018a – U, Th; 2018b – Rb, Ga, Cs; 2019 – Sb, W, Li; 2021 – Mg); Fabian *et al.* (2014 – pH; 2017 – Pb); Jordan *et al.* (2018 – Ni); Matschullat *et al.* (2018 – C, N, S); Hoogewerff *et al.* (2019 – 87Sr/86Sr), and Xu *et al.* (2019 – TOC, pH).

Harmonised high quality soil geochemical data sets

The GEMAS project has produced high quality exposure data for chemical elements across Europe that are harmonised with respect to: (1) land-use (agricultural soil, 0–20 cm and grazing land soil, 0–10 cm) – ***Figures 1 & 2***; (2) spatial scale (homogeneous sampling density of 1 site/2500 km^2, i.e., a grid of 50 × 50 km was used (EGS-GWG, 2008; Reimann, 2014); (3) sample preparation (<2 mm grain size), and sample splitting in the same laboratory (Mackovych and Lucivjansky, 2014), and (4) analytical methodology: all samples for the same suite of elements and physicochemical parameters were analysed in the same laboratory, namely (a) aqua regia extraction (ICP-MS 53 elements), (b) total (X-ray fluorescence, 41 elements), (c) mobile metal ion cold leach (MMI®, 55 elements), (d) lead isotope ratios, (e) pH (0.01M $CaCl_2$), (f) total organic carbon, total carbon, total sulphur, effective cation exchange capacity (eCEC at pH of the soil, silver thiourea method), (g) mid-infrared (MIR) spectra, (h) texture (sand, silt, clay) and (i) partitioning coefficients (k_d-values) for selected elements (Reimann *et al.*, 2009, 2011, 2012b; Birke *et al.*, 2014b). Quality control of all analytical results is documented in three publicly available reports (Reimann *et al.*, 2009, 2011, 2012b).

Figure 2: Photographs of (a) agricultural soil with cabbages, Hellas, and (b) grazing land soil with sheep grazing, Larnaca district, Cyprus.

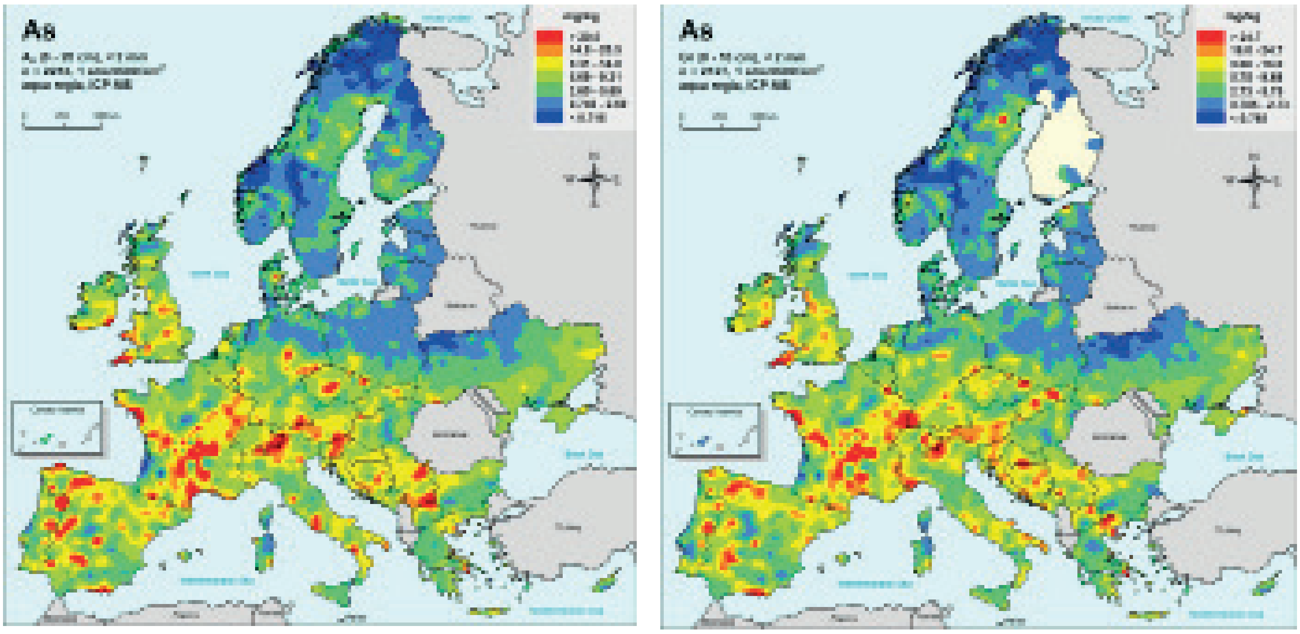
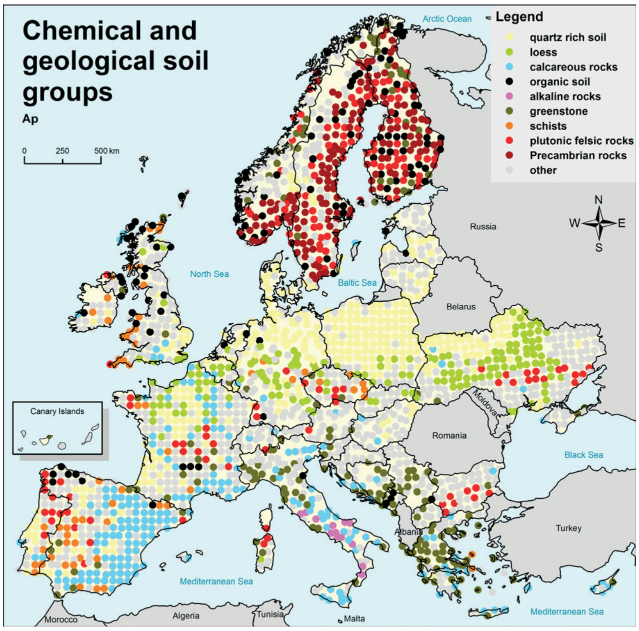


Figure 3: Geochemical maps showing the distribution of arsenic (As) in (a) agricultural soil and (b) grazing land soil (Reimann et al., 2014c, Fig. 11.9.5, p.154). Note the distinct north-south differences, and the comparable results of the two different sample types.

Large North-South differences

A major spatial difference in geochemical patterns is observed in the concentration of many chemical elements between the soil of northern and southern Europe. The young soil from northern Europe has 2 to 3 times lower element concentrations than the more mature, weathered and older soil in southern Europe. The arsenic (As) maps of agricultural and grazing land soil show this feature clearly with higher concentrations in southern and western Europe compared to northern Europe (***Fig. 3***). When comparing the geochemical maps with the geological map (***Fig. 4a***), the boundary between northern and southern Europe coincides remarkably well with the maximum extent of the last glaciation (***Fig. 4b***).



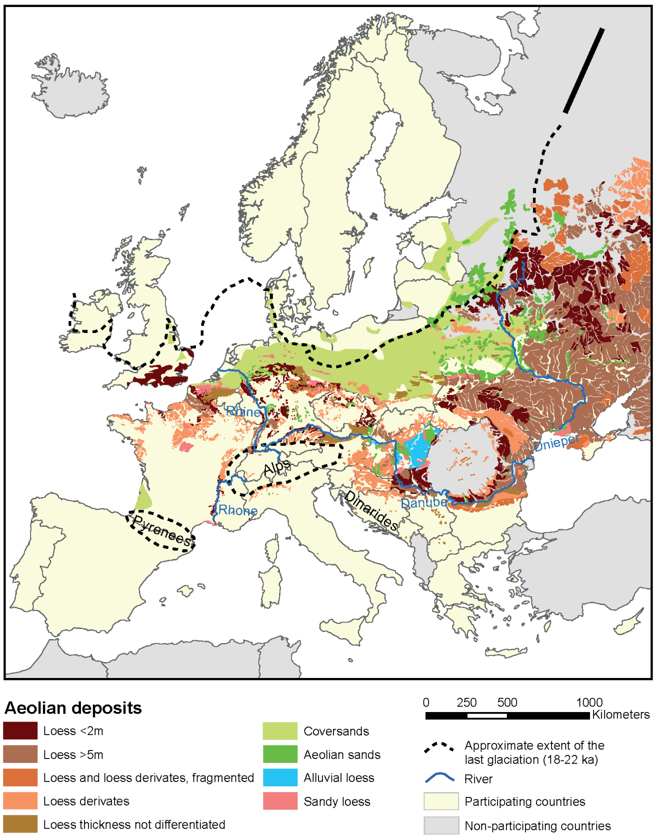


Figure 4: Maps showing (a) parent materials chemical and geological soil groups of agricultural soil (Ap) samples (Birke et al., 2014c, Fig. 10.8, p.98), and (b) distribution of aeolian deposits with maximum extent of the last glaciations (Weichset 18-22 ka) from Scheib (2014, Fig. 9.1, p.162); loess data for continental Europe redrawn from Haase et al. (2007); loess of southern Britain are based on Antoine et al. (2003), and generalised extent of coversand is based on Kasse (1997), Zeeberg (1998), and Bertran et al. (2009).

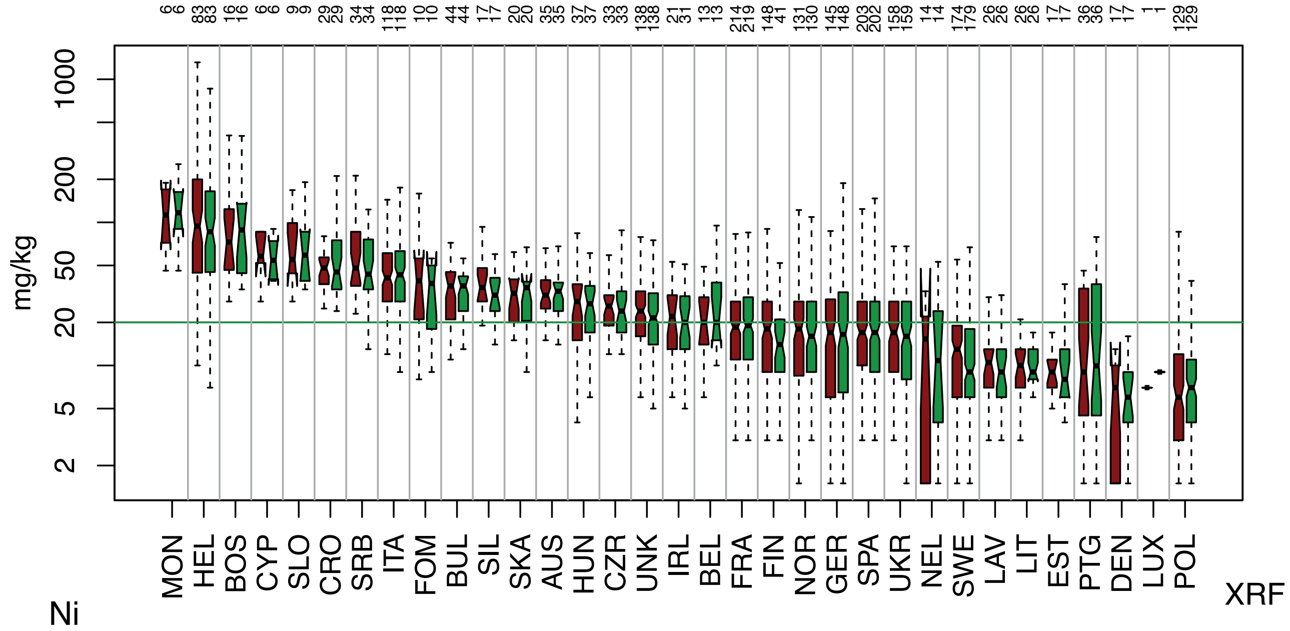


Figure 5: Boxplot comparison of nickel (Ni) concentrations in agricultural (Ap - dark red) and grazing land (Gr - green) soil samples of Europe (from Reimann et al., 2014c, Fig. 11.39.4, p.327). To focus on the main body of data the boxplots are shown without outliers (i.e., values 1.5 times the interquartile range above the upper quartile and below the lower quartile). The boxplots are ordered according to decreasing median values. The number of samples collected in each country is indicated on the top of the diagram. Countries: AUS: Austria; BEL: Belgium; BOS: Bosnia and Herzegovina; BUL: Bulgaria; CRO: Croatia; CYP: Cyprus; CZR: Czechia; DEN: Denmark; EST: Estonia; FIN: Finland; FOM: North Macedonia; FRA: France; GER: Germany; HEL: Hellas (Greece); HUN: Hungary; IRL: Republic of Ireland; ITA: Italy; LAV: Latvia; LIT: Lithuania; LUX: Luxembourg; MON: Montenegro; NEL: The Netherlands; NOR: Norway; POL: Poland; PTG: Portugal; SIL: Switzerland; SKA: Slovakia; SLO: Slovenia; SPA: Spain; SRB: Serbia; SWE: Sweden; UKR: Ukraine; UNK: United Kingdom. The green line shows the median concentration at 20 mg/kg Ni for both Ap and Gr soil samples.

Two different sample materials deliver comparable results

Two different sample materials, ploughed soil (0–20 cm) and grazing land soil (0–10 cm), taken at separate locations at a density of 1 site/2500 km² all over Europe and with different depth sampling ranges, deliver very comparable distribution maps of chemical elements. The two maps of arsenic (As) distribution in agricultural and grazing land soil samples illustrate this feature very well (***Fig. 3***). It is apparent that low sample density mapping results in robust maps.

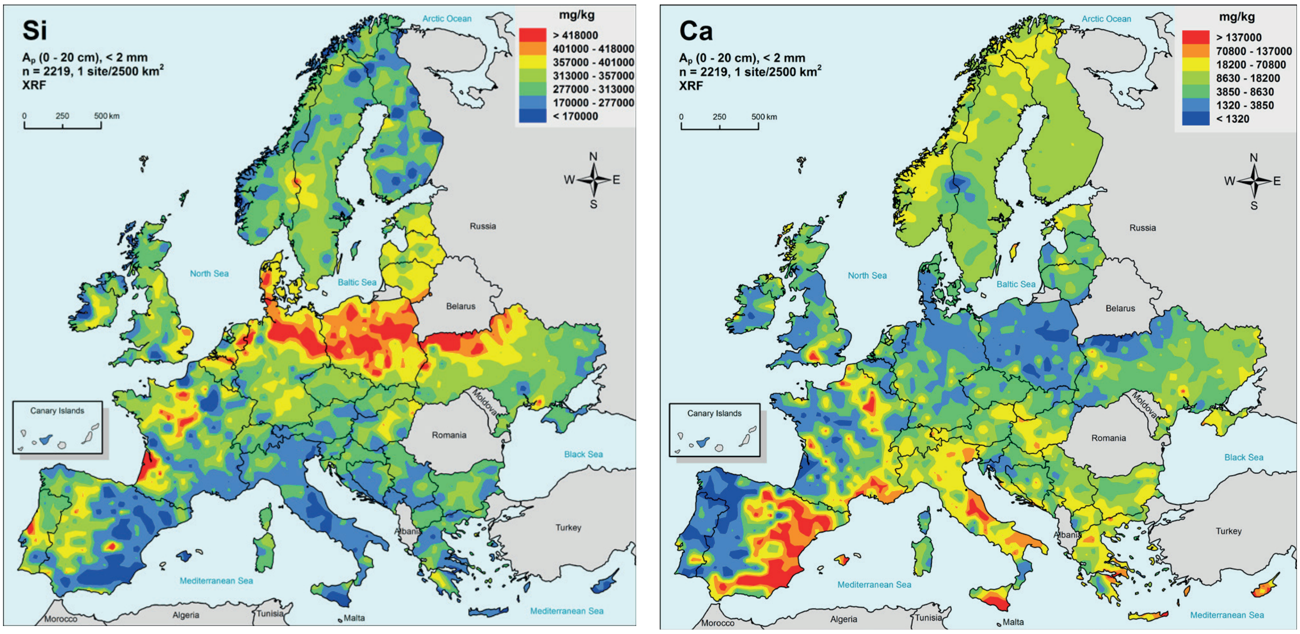


Figure 6: Total concentrations of (a) silicon (Si) and (b) calcium (Ca) in agricultural (Ap) soil samples, determined by X-ray fluorescence (XRF). From Reimann et al., 2014c, Figs. 11.51.5, p.399 & 11.16.5, p.200, respectively.

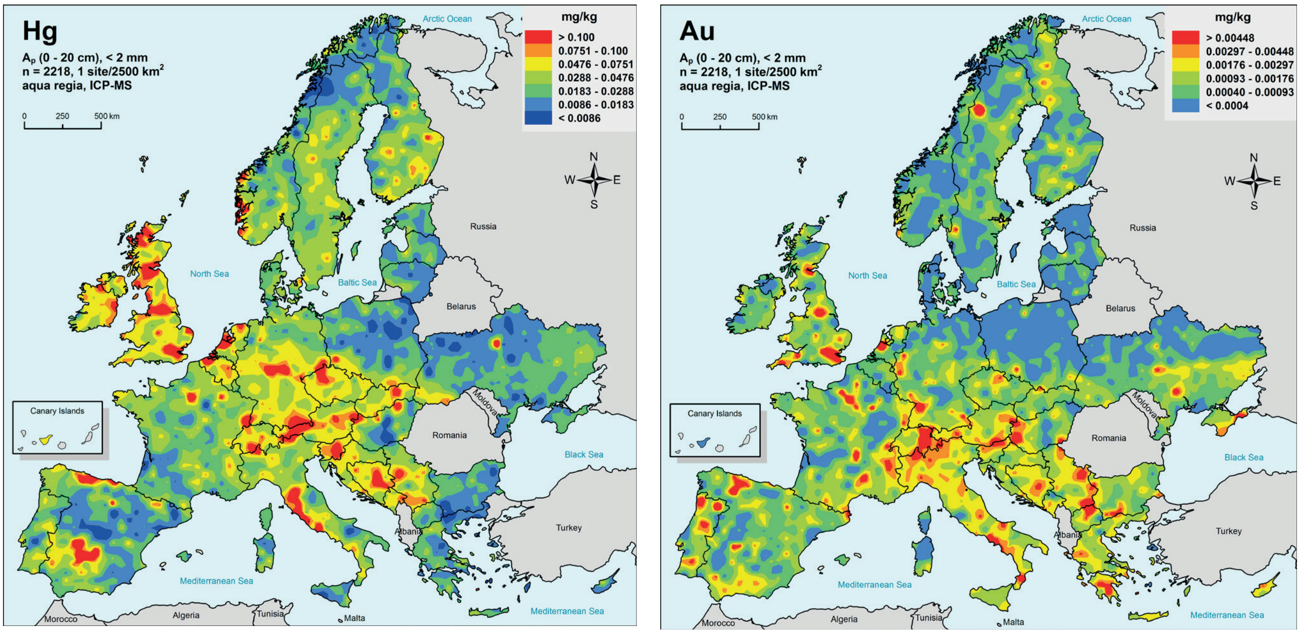


Figure 7: Geochemical maps showing the distribution of (a) mercury (Hg) and (b) gold (Au) in agricultural soil samples (Ap horizon) of Europe. From Reimann et al., 2014c, Figs. 11.29.5, p.269 & 11.10.5, p.161, respectively.

Substantial differences among country soil median values

Major differences are observed in elemental median values of agricultural and grazing land soil samples in the different European countries (***Fig. 5***). On average, there is a sixfold difference in the median concentration of the elements among the 33 countries sampled. Several elements show even substantially larger differences, up to a factor of more than 100 times. For nickel (Ni) (***Figure 5***), the lowest median value is observed in Poland (about 5 mg/kg), and the highest in Montenegro (almost 100 mg/kg).

Given these large natural differences, it is exceedingly difficult to define a single European background value for each element. This regionality is a crucial factor to consider in soil legislation, which sets out to determine threshold or action levels for chemical elements for all European Union countries.

The impact of geology

Geology, or better the distribution of parent materials for soil formation, plays a key role in determining the patterns observed on the geochemical maps. Most geochemical maps for metals are dominated by anomalies related to single ore deposits or metallogenic provinces. Soil developed on the sediments of the last glaciation, on chalk and limestone, felsic and mafic igneous rocks (e.g., granite, alkaline igneous intrusions) or black shale, all have their own characteristic geochemical signature that can be detected on the maps. For example, the high Si concentrations in soil are observed over the thick quartz-rich sediments of the last glaciation in north-central Europe, derived from the erosion of Fennoscandian silica-rich bedrock (***Fig. 6a***). Areas underlain by calcareous rocks (chalk, limestone, marble) are indicated by high calcium (Ca) concentrations on the map (***Fig. 6b***), e.g., southern England, Paris basin, Cevennes and Provence-Alpes-Côte d'Azur in southern France, eastern Spain and the Apennines in Italy. Even the principal geological difference between Fennoscandia and the rest of Europe is reflected on the Ca map, i.e., the minor occurrence of carbonate rocks in the Archaean and Precambrian rocks in Fennoscandia and their widespread occurrence in the Palaeozoic-Mesozoic-Tertiary formations of the rest of Europe. On a more local scale, the area with low Ca concentrations at the Norwegian/Swedish border (***Fig. 6b***) marks a sandstone unit, which is indicated by elevated Si concentrations (***Fig. 6a***).

The impact of human activities

For a few elements, typically those associated with human activities (e.g., mercury (Hg), lead (Pb) but even silver (Ag) and gold (Au)), some (but far from all) European cities are noticeable by the elevated element concentrations in the agricultural soil samples taken in their vicinity. For example, the surrounding areas of London, Paris and Rotterdam are marked by high Hg values in agricultural soil (***Fig. 7a***), a feature shown on other geochemical distribution maps, e.g., Pb, Ag, Au. Kiev is also clearly discernible by a Hg anomaly, which is most likely due to the presence of a mercury processing facility right in the city. London, Paris and Amsterdam are indicated by Au anomalies (***Fig. 7b***). Otherwise, an anthropogenic impact is difficult to detect at the mapping scale of the GEMAS project (1 sample site/2500 km²). The location of most metal smelters or coal-fired power plants remains invisible on the continental-scale geochemical maps.

The Hg anomalies in the Rome/Naples agglomerations in Italy are presumably of natural origin and due to the occurrence of alkaline volcanic rocks (***Fig. 7a***). Large European Hg deposits like Almadén in the Spanish province of Ciudad Real, the Asturias mining district in NW Spain, and Monte Amiata in the southern Tuscany region of Italy are also marked by distinct Hg anomalies (Ottesen *et al.*, 2013). Many of the Hg anomalies in Scandinavia, along the west coast of Scotland and Ireland are due to the occurrence of organic matter-rich soil and the natural enrichment of Hg in humus.

Generally, most of the high element values observed on the GEMAS geochemical maps are clearly related to natural metal occurrences or to specific rock types that are enriched in these elements. Overall, the human impact on the quality of agricultural and grazing land soils is remarkably low at the continental-scale of the GEMAS project (1 sample site/2500 km^2).

In terms of the few existing national soil action levels for agricultural soil in Europe, an important observation is that in general very few soil samples deliver results that are above any known action level.

Risk assessment

How can toxicologically relevant element concentrations in soil samples be detected? The answer to this question is the existence of harmonised and validated measurements of element concentrations in agricultural and grazing land soil samples, in combination with results for parameters (such as pH, CEC, TOC) determining the availability of the elements in soil, allowing for the first time a realistic risk assessment of trace elements in soil at the European scale (***Fig. 8***). The generated data sets have been used by several European metal industries under the European REACH regulation to assess the risks of the metals they produce to organisms living in agricultural and grassland soils in Europe (Oorts & Schoeters, 2014; Oorts *et al.*, 2016). In fact, an exceedingly small proportion of the GEMAS project soil samples exhibit a risk due to high metal concentrations.

Risk characterisation ratios (RCRs) are calculated as the ratio of measured aqua regia-extractable Cu concentration over the corresponding predicted no-effect concentration for risk characterisation (PNEC). The PNECs, or ecological soil standards, can be compared with prevailing exposure concentrations in soil to identify areas with potential risk (Oorts *et al.*, 2016). For copper (Cu), most of the agricultural soil samples at risk were taken in vineyards (use of Cu-based pesticides) (Oorts & Schoeters, 2014).

Is diffuse contamination a serious threat to soil quality?

The European Commission has identified diffuse contamination as one of the eight threats to sustainable soil quality in Europe (EC, 2002). The GEMAS geochemical maps demonstrate that the impact of diffuse contamination, especially long-range transboundary air pollution, on the quality of European agricultural soil is vastly overestimated at present. Contamination from anthropogenic sources plays a key role at a much more local scale (e.g., see above the impact of cities like London and Paris on the Hg concentrations in soil), and sometimes at the regional scale but remains undiscernible at the continental scale. At the European scale, the GEMAS geochemical maps show that the occurrence of ore deposits, geology (certain rock types enriched in specific elements) and climate play the key role in determining the observed element spatial distribution patterns. Surprisingly, neither agriculture nor diffuse contamination have affected the (semi-) total chemical composition of European agricultural soil at the continental scale (Fabian *et al.*, 2017; Reimann & Fabian, 2021). However, the weak cold extraction (MMI®) method showed potential effects of, for example, Cd concentrations from fertilisers in some agricultural areas of Europe (Reimann *et al.*, 2014c; Mann *et al.*, 2015). These observations indicate that diffuse contamination is a more complex issue than one might expect, and the superimposed effects of anthropogenic activities on soil should always be calibrated against the local natural geochemical background.

Health implications: element deficiency needs more attention

The interplay between element toxicity and deficiency has important consequences for health implications. Many trace elements play a vital role in the health of plants, animals and humans (Kabata-Pendias & Mukherjee, 2007; Alloway, 2013). For instance, molybdenosis is a disease affecting ruminants such as cattle and sheep but also wild grazing animals, mainly deer and moose. It is caused by grazing on land with increased molybdenum (Mo) concentrations in soil (***Fig. 9a***). The high intake of Mo results in a copper (Cu) deficiency, which leads to many severe health prob-

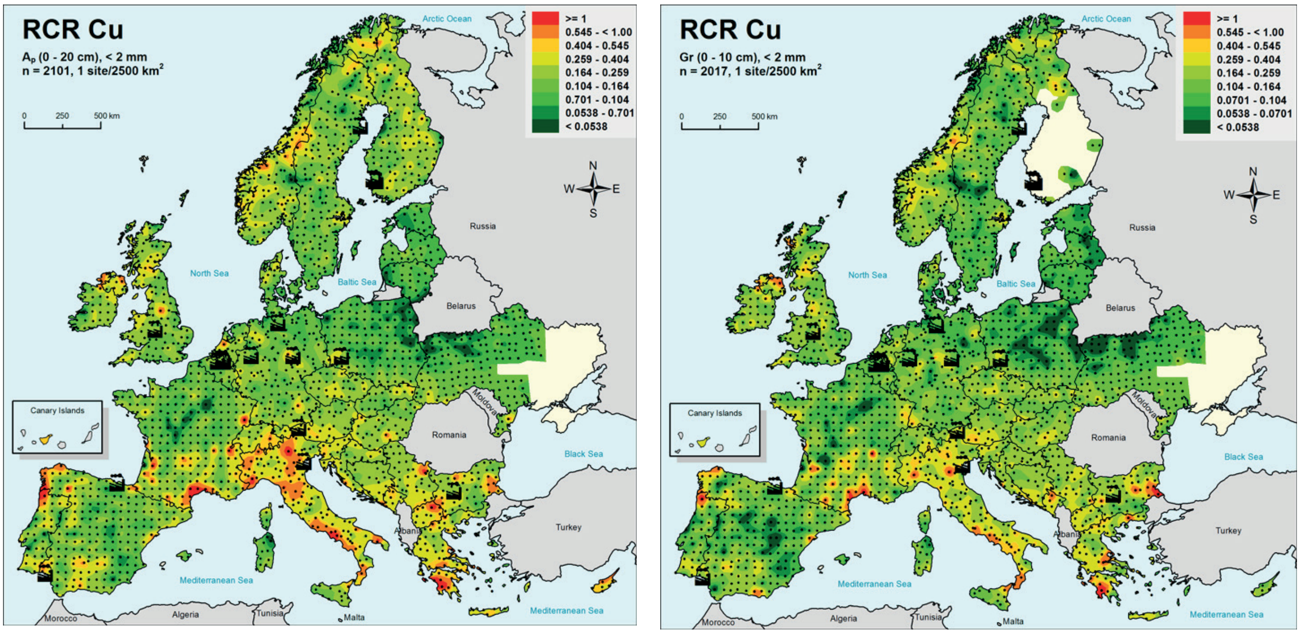


Figure 8: Distribution of risk characterisation ratios (RCR), calculated as the ratio of measured aqua regia extractable concentration of Cu with respect to the corresponding predicted no-effect concentration for risk characterisation (PNEC) for (a) agricultural soil, and (b) grazing land soil. Only a few isolated sites are predicted to be at risk for Cu (i.e., risk characterisation ratio, RCR >1). About 1.5% and 1.3% of sample sites for (a) agricultural and (b) grazing land soil, respectively, were predicted to be at risk. From Oorts & Schoeters, 2014, Fig. 12.7, p.198, with addition of large smelters.

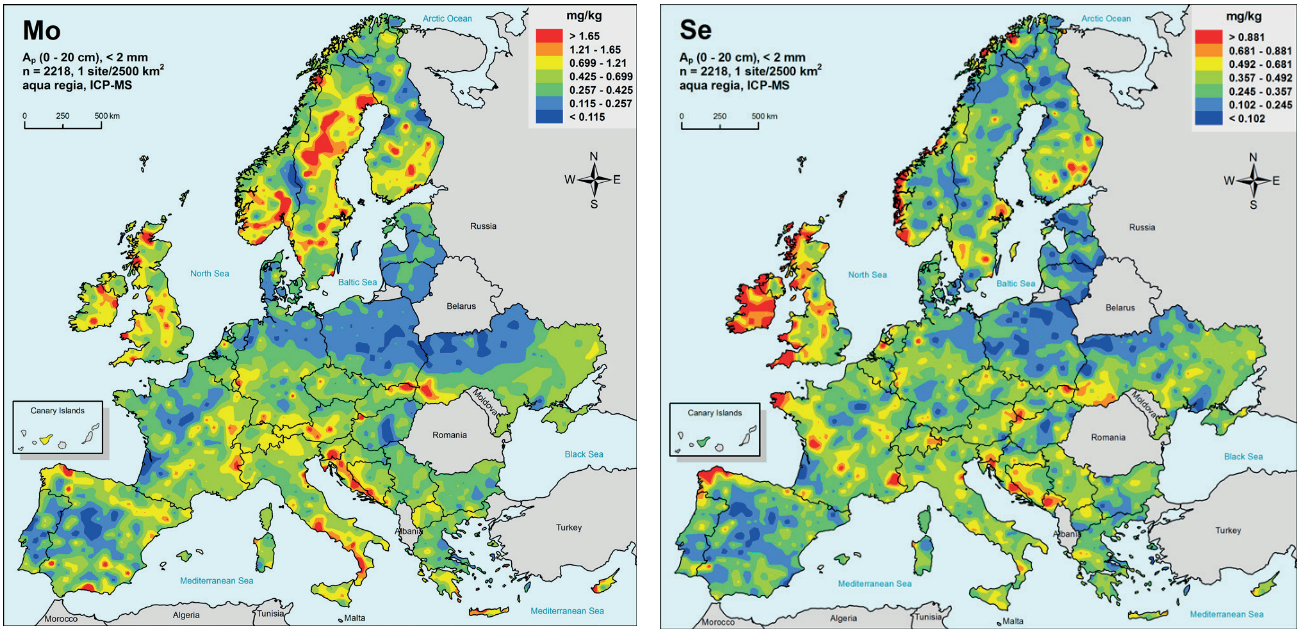


Figure 9: Geochemical maps showing the distribution of (a) molybdenum (Mo) and (b) selenium (Se) in agricultural soil samples. From Reimann et al., 2014c, Figs. 11.36.5, p.311 & 11.50.5, p.393, respectively.

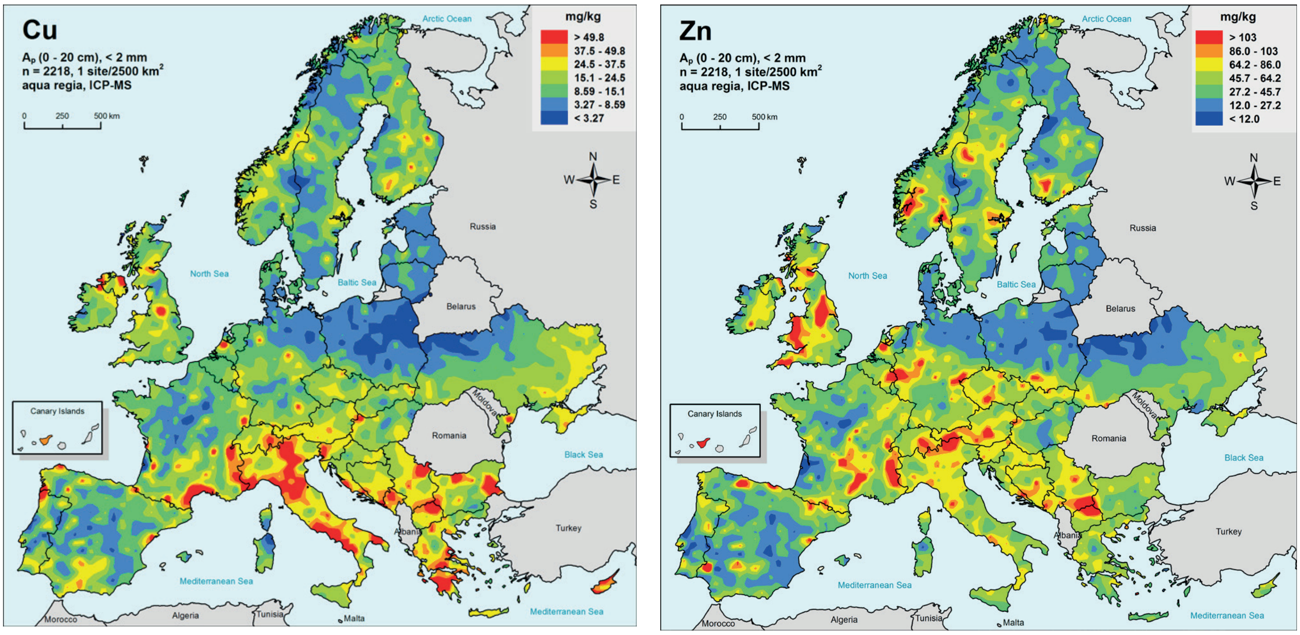


Figure 10: Geochemical maps showing the distribution of (a) copper (Cu) and (b) zinc (Zn) in agricultural soil samples. From Reimann et al., 2014c, Figs. 11.23.5, p.237 & 11.63.5, p.467, respectively.

lems, including organ failure and death. The massive death incidents of moose in Sweden in the 1980s and 1990s were likely caused by liming to prevent acidification of forest soil, which resulted in Mo mobilisation, which in turn reduced Cu uptake in the diet of the moose (Broman *et al.*, 2002).

Another example is selenosis, a poisoning of livestock caused by the ingestion of selenium (Se), which can be enriched in some plants by microorganisms or in soil due to specific climatic conditions. In Europe, excessive Se concentrations occurring along coastal areas of United Kingdom, NW Spain, NW France and Norway are due to the steady input via marine aerosols in combination with a strong affinity to bind to organic matter in soil (***Fig. 9b***). The highest Se enrichment in European agricultural soil occurs in Ireland. However, at the continental scale Se deficiency may be a larger problem than Se toxicity.

Copper (Cu) and zinc (Zn) are two metals that are usually of concern when they occur at high levels, whether their origin is natural or anthropogenic (***Fig. 10***). Both Cu and Zn are, however, important nutrients and at the European scale deficiency of these elements in soil may be a much larger concern warranting attention than their toxicity (e.g., Cu and Zn have high statutory action values, which are rarely observed in agricultural and grazing land soil – see Appendix A in Reimann *et al.*, 2014d).

Overall, very few agricultural and grazing land soil samples reach alarming concentrations where toxicity may become of concern. However, more than 10% of the GEMAS soil samples contain such low concentrations that deficiency is an issue for optimum plant and animal health and productivity may be of much greater concern.

Forensic applications

The GEMAS data sets deliver valuable information for forensic sciences and intelligence. Multi-element data sets, including some isotope systems, can be used to trace the origin of food or even human bodies (Morgan & Bull, 2006; Pye, 2007; Hoogewerff *et al*., 2019; Caritat *et al*., 2021). It is, thus, not surprising that forensic units of, for example, Scotland Yard and the Royal Canadian Mounted Police have expressed interest in the GEMAS data sets.

Discussion and conclusions

To make the GEMAS project possible 65 organisations – from almost all of the Geological Surveys of Europe, other State and contract research organisations, universities to industry – have cooperated to produce fully harmonised, strictly quality controlled and freely available data sets at the scale of a continent. For the first time, the GEMAS project provides fully harmonised data for chemical element concentrations and soil properties known to influence their bioavailability and toxicity in agricultural and grazing land soils, the productive soils of Europe. Society has, therefore, a valuable reference data set, a 2008 timeline, to monitor future changes in its agricultural and grazing land soils, caused by both human or natural causes, and a set of reference soil samples for future research. Such an archive is invaluable for land use planning, industrial development, environmental protection, risk assessment, forensic science, agriculture and food tracing. In the case of a major disaster, natural or human-induced, the European authorities have a reference data and a sample set to assess the impact of such an event. Furthermore, a better awareness of element deficiency levels can lead to an increase in productivity and animal health.

To validate the veracity of the GEMAS data sets, results have been compared with residual and alluvial soil samples collected by another pan-European project, carried out by the Geochemistry Expert Group of EuroGeoSurveys, the FOREGS Geochemical Atlas of Europe (Salminen *et al*., 2005; De Vos, Tarvainen *et al*., 2006), which displays similar geochemical patterns. Moreover, the European Commission's Joint Research Centre confirmed that high variation in Hg concentrations across Europe can be mostly explained by soil organic carbon content, vegetation, soil parent material and other natural soil-related processes rather than large scale diffuse pollution. Based on the results of the LUCAS project soil samples (0-20 cm), it was found that some mining activities and coal combustion sites have a regionally important role in the Hg distribution (Ballabio *et al*., 2021).

The patterns displayed on the geochemical maps discussed in this study are mainly related to the soil parent materials, with distinct differences observed between the lithology of northern and southern Europe. The concentration break for most elements coincides with the southern limit of the last glaciation, i.e., lower element values to its north and elevated values to its south. Of course, for some elements (e.g., Se) their spatial distribution depends on other factors, such as proximity to the sea and soil organic matter.

The recent FAO and UNEP report about the "Status of soil pollution in Europe" (FAO and UNEP, 2021) refers to a European Environmental Agency report (EEA, 2019) and states that "agriculture significantly contributes to diffuse soil and water pollution in Europe" (Eugenio and Ronzan, 2021, Chapter 8), which according to the citation has been taken from a European Environmental Agency report (EEA, 2019). Two metals are given as examples: Cd from mineral fertilisers and Cu from fungicides. This short statement does not consider the results of the GEMAS, FOREGS and LUCAS projects that show the importance of understanding geology, soil parent material and other soil properties, as well as the analytical method applied while assessing soil contamination at the European scale. Anomalies of Cu in vineyards and Cd in heavily fertilised areas of Europe are actually visible on the maps of the GEMAS project but certainly not at the continental scale; at best they are limited to the regional and rather the local scale.

As diffuse contamination is a much discussed topic, it is worth quoting Fabian *et al.* (2017), who make the following introductory statements:

"On the basis of experience from the local scale, for example from the proximity of a metal smelter, it is widely assumed that contamination always results in unusually high concentrations of the emitted element in soil, and monitoring activities are focusing on extreme values. However, dependent on signal intensity local contamination becomes indistinguishable from the natural background variation at a characteristic distance from the source, usually measured in metres to some kilometres, and in extreme cases 100–200 km. It is therefore a major challenge to identify and quantify diffuse contamination in soil as distinguished from local or regional contamination, because it cannot be clearly separated from a large natural background variation" (p. 6719).

In their conclusion, Fabian *et al.* (2017) state that "diffuse soil contamination at the continental-scale remains invisible in continental scale geochemical maps because the natural variation is still considerably larger and dominates spatial patterns of high concentrations. This solves the puzzle that in spite of substantial anthropogenic emissions, geochemical maps of Pb at the continental scale consistently reflect natural conditions, usually both geology and climate. Pb contamination therefore is rarely marked by high total Pb concentration, but rather by overabundant lower and medium concentrations of Pb" (p. 6725).

Hence, international organisations such as EEA, FAO and UNEP should be extra careful about reporting 'global pollution analyses' in their reports. The scale of anthropogenic induced contamination can be either overlooked or overestimated if the natural geochemical background is not taken into account.

As concluding remarks, the GEMAS project, has produced data sets with well comparable results for two soil types, agricultural (0-20 cm) and grazing land (0-10 cm) sampled at the European scale, leading to several major findings.

- A major difference in soil chemical composition is observed between the young northern and older southern European soil;
- On average there is a sixfold difference in the median concentration of elements among the 33 participating countries (up to a factor of more than 100-fold);
- Spatial element distributions depend mainly on geology and climate;
- High trace element concentrations in soil are most often related to mineral deposits and metallogenic provinces;
- The anthropogenic impact is hardly detectable at the European scale;
- Some cities (e.g., London, Paris) cause anthropogenic trace element anomalies (e.g., Au, Pb, Hg) in their near surroundings and element concentrations decrease rapidly with distance from the source;

- Risk assessment for metals like Cu shows that few soil samples have such high concentrations that they pose a potential toxic risk for soil organisms; most of these samples were taken in vineyards;
- Several important trace elements (minor nutrients, e.g., Cu, Zn) show such low levels over sizeable tracts of land in Europe that trace element deficiency is clearly an issue of concern.

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Global assessment of soil pollution: The need for standardized methods

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Reliable analysis and quantification of components in soil is essential in order to determine if the soil is 'fit for purpose'. Soil provides the basis for our existence, but not all soils can be used for every purpose. This is sometimes obvious, but often it is necessary to characterize the soil in order to identify what soil use is possible. For agricultural use, domestic housing, recreation or industries, just to mention a few, specific soil conditions apply and often governmental regulations are in place. Reliable characterization methods are therefore of major importance. Standardization of such reliable methods is the objective of the European standardization committee CEN/TC 444 – Environmental characterization of solid matrices and the worldwide standardization committee ISO/TC 190 – Soil quality.

Une analyse et une quantification fiables des composants du sol sont essentielles pour déterminer si le sol est « adapté à l'usage ». Le sol constitue la base de notre existence, mais tous les sols ne peuvent être utilisés à toutes les fins utiles. Ceci est parfois évident, mais il est souvent nécessaire de caractériser le sol afin d'identifier quelle utilisation du sol est possible. Pour l'usage agricole, l'implantation de logements, les loisirs ou les industries, pour n'en citer que quelques-uns, des conditions de sol spécifiques s'appliquent et des réglementations gouvernementales sont souvent en place. Des méthodes de caractérisation fiables sont donc d'une importance majeure. La normalisation de telles méthodes est l'objectif du comité européen de normalisation CEN/TC 444 – Caractérisation environnementale des matrices solides et du comité mondial de normalisation ISO/TC 190 – Qualité des sols.

El análisis y la cuantificación confiables de los componentes del suelo son esenciales para determinar si el suelo es "apto para su propósito". El suelo proporciona la base de nuestra existencia, pero no todos los suelos pueden utilizarse para todos los fines. Esto a veces es obvio, pero a menudo es necesario caracterizar el suelo para identificar qué uso del suelo es posible. Para uso agrícola, vivienda doméstica, recreación o industrias, solo por mencionar algunas, se aplican condiciones específicas del suelo y, a menudo, existen regulaciones gubernamentales. Por tanto, los métodos de caracterización fiables son de gran importancia. La estandarización de métodos tan confiables es el objetivo del comité de estandarización europeo CEN / TC 444 - Caracterización ambiental de matrices sólidas y del comité de estandarización mundial ISO / TC 190 - Calidad del suelo.

Introduction

The characterization of soil quality is essential in the assessment of its beneficial characteristics (e.g. for food production), but also to determine the potential adverse effects when confronted with polluted soil. Soil quality can be defined in term of its content of nutrients, (heavy) metals or chemical components, the potential leaching of these substances into ground and surface water, the availability for uptake by plants, animals and humans and in terms of the mobility of components and consequent distribution of these substances in the environment. Depending on the component and its concentration level and availability, it can either have positive or adverse effects on the soil quality. Characterization and assessment of soil quality is therefore important.

Providing reliable and well established international (ISO) and European (CEN) standards for the characterization of soil, is exactly the job of the technical committees ISO/TC 190 – Soil Quality and CEN/TC 444 – Environmental characterization of solid matrices.

The world of standardization

Standardization is a process of coming to a generally accepted agreement amongst stakeholders on a specific topic. Standardization is all around us, and facilitates many aspects of life. Standards allow markets for a specific product, while markets will lead to competition for best quality and lowest prices. One arbitrarily chosen example is hexagon head screws according to ISO 4017; if e.g. M10 screws are ordered from any manufacturer, they all will fit and have the same dimensions.

If no international standards are available, or national standards are not harmonized internationally, problems may occur. Everybody who has travelled abroad will know the problem of the variety of AC power plugs and sockets around the world. This can be solved by using adapters, but still, you need to be aware of the need to have the appropriate adapter with you.

Standardization is a democratic and public process. As this process is quite complex, National Standardization Bodies (NSBs) support the work and organize web-based platforms for the exchange of information. NSBs are non-governmental registered organizations and are open to everyone.

The standardization process itself is performed by experts in the specific field, usually in a working group (WG). They discuss in what way reliable measurements can be performed and propose draft standards. These are published within the technical committee, and comments can be submitted by everyone via the NSBs. These comments are discussed in the WG – accepted or rejected – and at the end of a standardization process a standard is published

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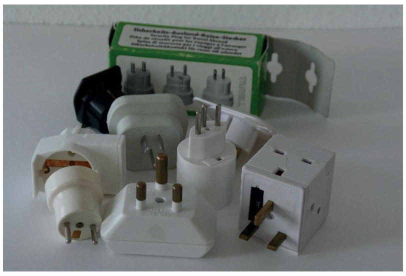

Figure 1: Collection of travel adapters (photo by Klaus Liphard).

Table 1: Examples of National Standard Bodies (NSBs) around the world (source: ISO website).

Country/Territory	*Acronym*
Austria	*ASI*
Czech Republic	*UNMZ*
Canada	*SCC*
Germany	*DIN*
Japan	*JISC*
Korea (Republic of)	*KATS*
Netherlands	*NEN*
United Kingdom	*BSI*

after acceptance by a majority of voters in a final voting process amongst the participating NSBs. This process applies to all three levels at which standardization is organized: national, regional and worldwide.

The basis is the work on the national level, facilitated by the responsible NSB. Each country or territory has its own standardization body; see ***Table 1*** for some examples.

On the regional level there is sometimes a formal cooperation between NSBs, providing common standards for that region. An example is the European Committee for Standardization CEN, which provides European Standards (labelled 'EN [number]').

Finally, standardization at worldwide level runs through the International Standardization Organization (ISO). The outcome is International Standards (labelled 'ISO [number]'). The NSBs nominate national experts to participate on both European and worldwide standardization levels. This article introduces the work of two technical committees working towards standardization related to soil: the ISO committee 190 and the European committee 444.

ISO/TC 190 – Soil Quality

In the 1980s, awareness regarding soil protection began to increase. While water and air react visibly faster to negative influences, soil can accumulate larger amounts without this being noticeable. Nevertheless, adverse effects are present and need to be detected by robust and sensitive methods.

For that purpose, the technical committee ISO/TC 190 – Soil Quality was established in 1985, and had its first meeting in The Hague (the Netherlands) in 1986. Currently, ISO/TC 190 has 28 actively participating members (NSBs) and 29 observing members (without the right to vote). It is currently made up of three subcommittees (SCs) with in total seventeen active working groups (WGs). The structure is depicted in ***Figure 2***.

As of early September 2021 ISO/TC 190 has published – coincidently – 190 standards for the characterization of soil, while another 19 standards are under development. These standards cover a wide variety of topics, including the vocabulary, sampling, sample storage, transport and preservation, physical and biological characterization, the determination of both organic and inorganic components as well as leaching and assessment methods. Some recently published examples are provided in ***Table 2.***

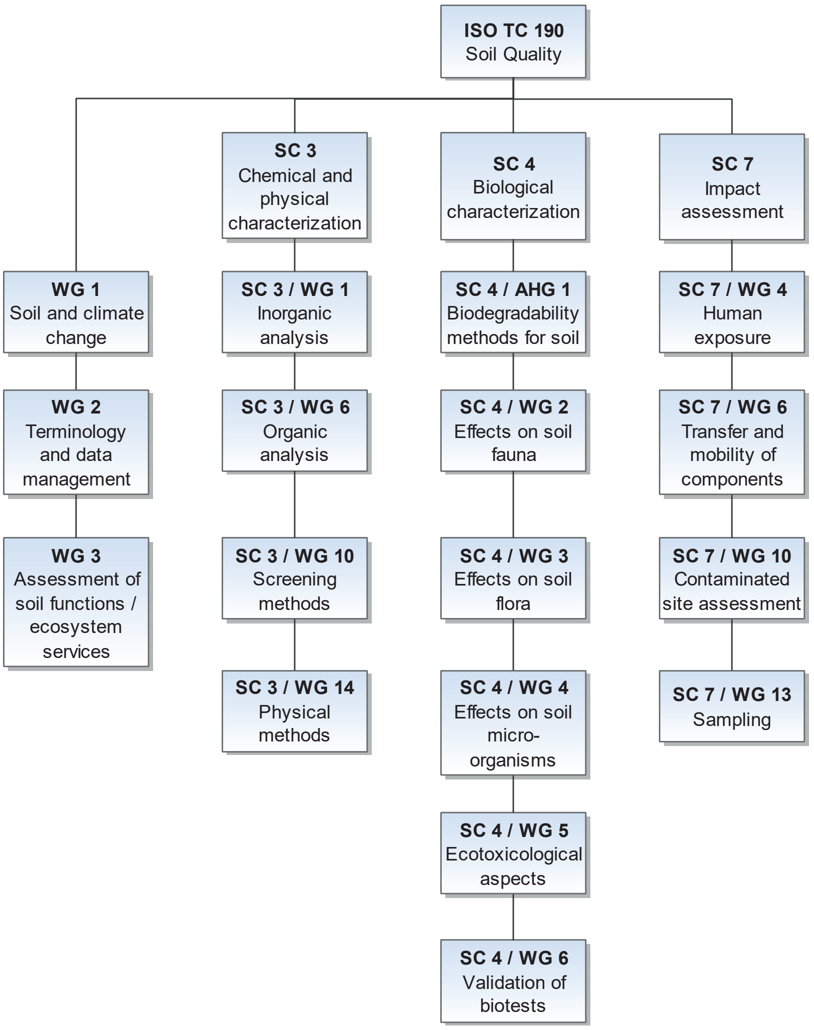

Figure 2: Structure of ISO/TC 190 - Soil Quality.

Table 2: Examples of recently published ISO standards under ISO/TC 190 - Soil quality.

ISO number	*Title*
ISO 18400-101:2017	*Soil quality — Sampling — Part 101: Framework for the preparation and application of a sampling plan*
ISO 15192:2021	*Soil and waste — Determination of Chromium(VI) in solid material by alkaline digestion and ion chromatography with spectrophotometric detection*
ISO 23266:2020	*Soil quality — Test for measuring the inhibition of reproduction in oribatid mites (Oppia nitens) exposed to contaminants in soil*
ISO 21365:2019	*Soil quality — Conceptual site models for potentially contaminated sites*

CEN/TC 444 – Environmental characterization of solid matrices

CEN/TC 444 – Environmental characterization of solid matrices was established in 2015, but unlike ISO/TC 190, it had a series of predecessors. Originally, the European field of environmental standardization was matrix oriented; there were separate technical committees (TCs) for soil and waste. However, from an analytical point of view the characterization methods for these matrices were quite similar. This was further investigated in the EU-funded project 'Horizontal', which resulted in the development of harmonized European standards for multiple matrices (sludge, treated biowaste and soil). To integrate the results of project 'Horizontal' into the CEN system, a temporary Project Committee was established (CEN/TC 400 – Project Committee – Horizontal standards in the fields of sludge, biowaste and soil), but with the end of project 'Horizontal' this Project Committee came to the end of its lifespan. At the same time, there was no TC that had a sufficiently large work area (sludge, biowaste and soil) to accommodate the standards that resulted from the project 'Horizontal'. This, together with the awareness that the efficiency of the standardization process could be enhanced, resulted in the disbandment of three CEN technical committees: CEN/TC 400, CEN/TC 292 – Characterization of Waste and CEN/TC 345 – Characterization of soils. Standards from these three TCs were transferred to the newly established CEN/TC 444. Currently CEN/TC 444 has 21 actively participating members (NSBs) and 25 observing members (without the right to vote).

CEN/TC 444 and its predecessors have published 168 standards, while another 23 standards are still under development. Part of these standards are single-matrix standards that still need to be withdrawn as a result of the multi-matrix standard that resulted from project 'Horizontal'. This is an ongoing process wherein the current state-of-the-art knowledge is included. However, it is important to note that not all standards within the working area of CEN/TC 444 are or can be multi-matrix standards. For example, even though the underlying principles are comparable, there are significant differences in the sampling of in situ soils and a stream of waste material. Therefore CEN/TC 444 accommodates both single- as well as multi-matrix standards.

Like ISO/TC 190, CEN/TC 444 has a wide variety of technical areas which are reflected in its organizational structure, as depicted in ***Figure 3***.

Cooperation between ISO/TC 190 and CEN/TC 444

As the work area of CEN/TC 444 includes standards for soil, there is a strong relation with ISO/TC 190. In fact, a large number of standards that have been developed by ISO/TC 190 have been adopted as European standards.

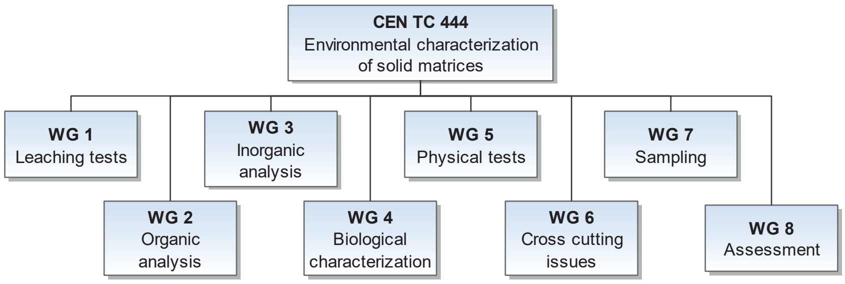

Figure 3: Structure of CEN/TC 444 - Environmental characterization of solid matrices.

As mentioned before, the matrix-orientated (vertical or sectoral) approach has been superseded by the multi-matrix (horizontal) approach. To ensure the best utilization of limited resources and to avoid duplicate work, ISO/TC 190 and CEN/TC 444 work closely together. Some multi-matrix standards are developed with ISO leading and CEN participation, for others it is vice versa. The result will be an EN ISO standard – an identical delivery in both organizations.

An example for an ISO-led process is the merger of two standards for the selection and application of screening methods. Originally a CEN method was developed for the application of screening methods for the swift characterization of waste materials. In parallel, a comparable ISO method was developed for soil. With the possibility to develop multi-matrix standards, this resulted in EN ISO 12404 'Soil and Waste — Guidance on the selection and application of screening methods'.

The corresponding example for a CEN-led process is the merger of two standards for the determination of elements by ICP/OES. Originally there was a CEN method for sludge, treated biowaste and soil, and an ISO method for soil. In a currently ongoing standardization effort, these two standards will be merged into a single EN ISO standard whose publication is scheduled for early 2023.

Fields of application of soil standards

As already mentioned in the introduction, soil characterization standards can be used in a large variety of different areas. The result of those measurements should not be a cause for dispute: they need to be reliable and fulfil the quality demands of the involved legislative framework. In such a situation, if legislative limits are exceeded, the discussion should be focused on the exceedance and not on the reliability of the method.

Contaminated areas can be a threat to the environment. This includes abandoned industrial sites, but also areas affected by airborne contaminants or flooding. Suspected contaminated areas need to be investigated in a multi-step approach including historical survey, sampling plan, sampling, analysis and assessment. The results have to be checked against governmentally set threshold and/or limit values. These results will be obtained by different methods for different purposes. This involves amongst others the total concentration of a specific compound in the soil, the amount of this compound that can leach into groundwater, or the oral intake by children on playgrounds.

In food and feed production, the quality of the agricultural soil plays an important role. On the one hand the farmer wants to maximize the crop production, but at the same time costs (e.g. for fertilizers) are to be limited while also the environment needs to be protected (e.g. protection against runoff from an excessive fertilizer load). But such decisions are not only up to the farmer. National and/or regional governments have adopted legislation to which the farmer has to comply, and this compliance can only be quantified through measurements.

Conclusions

Reliable results can only be obtained by reliable standardized methods. These methods are developed by national, regional and international organizations. Two technical committees, ISO/TC 190 – Soil Quality and CEN/TC 444 – Environmental characterization of solid matrices, play an important role in the characterization of soil. Their standards prove the validity of the slogan, "Once tested, accepted everywhere".

For further information:

- International Standards Organization: ***http://www.iso.org***
- List of ISO member National Standards Boards: ***https://www.iso.org/members.html***
- ISO/TC 190: ***https://www.iso.org/committee/54328.html***
- European Committee for Standardization: ***https://www.cencenelec.eu/***
- CEN/TC 444: ***https://standards.cencenelec.eu/dyn/www/f?p=205:7:0::::FSP_ORG_ID:2046877&cs=1C379FCFCAAF69B55CD86BA254B8F2F7F***

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A US Perspective on Soil Pollution: Observations, Conclusions, and Recommendations

Barney Paul Popkin[1]*

Soil is our gateway to civilization. We depend on our soil for vegetation, habitats, landscape, food, fiber, animal feed, wildlife, water and air quality, employment, cultural engagement, and our civilization's construction and physical construction. However, our once natural soils have largely morphed into anthropogenic or man-altered soil due to agriculture or construction processes. We are heavily regulated by "command and control" legislation and regulation, "polluter pays" policies, and somewhat influenced by information, education, outreach, public opinion, media, and environmental initiatives and litigation. These focus more on runoff and underground waters than on soil, and are often spotty, inconsistent, unenforced, and neglected. Besides information on commonly used methods, with a focus on MONA, and regulation in the United States, I offer observations and recommendations from the perspective of an advisor working in the US context.

Le sol est notre porte d'entrée vers la civilisation. Nous dépendons de notre sol pour la végétation, les habitats, le paysage, la nourriture, les fibres, l'alimentation animale, la faune, la qualité de l'eau et de l'air, l'emploi, l'engagement culturel et la construction physique (et imagée) de notre civilisation. Cependant, nos sols autrefois naturels, se sont largement transformés en sols anthropiques en raison de l'agriculture et de la construction. Nous sommes fortement guidés par une législation et une réglementation type « commandement et contrôle », des politiques de « pollueur-payeur », et que quelque peu influencés par l'information, l'éducation, la sensibilisation, l'opinion publique, les médias et les initiatives et litiges environnementaux. Celles-ci se concentrent cependant davantage sur le ruissellement et les eaux souterraines que sur le sol, et sont souvent inégales, incohérentes, non appliquées et négligées. Outre des informations sur les méthodes couramment utilisées (en mettant l'accent sur MONA) et la réglementation aux États-Unis, je propose ici des observations et des recommandations du point de vue d'un conseiller travaillant dans le contexte outre-Atlantique.

El suelo es nuestra puerta de entrada a la civilización. Dependemos de nuestro suelo para la vegetación, los hábitats, el paisaje, los alimentos, la fibra, la alimentación animal, la vida silvestre, la calidad del agua y del aire, el empleo, el compromiso cultural y la construcción y construcción física de nuestra civilización. Sin embargo, nuestros suelos una vez naturales se han transformado en gran medida en suelos antropogénicos o alterados por el hombre debido a la agricultura o los procesos de construcción. Estamos fuertemente regulados por leyes y regulaciones de "comando y control", políticas de "quien contamina paga", y de alguna manera estamos influenciados por la información, la educación, la divulgación, la opinión pública, los medios de comunicación y las iniciativas y litigios ambientales. Estos se centran más en la escorrentía y las aguas subterráneas que en el suelo y, a menudo, son irregulares, inconsistentes, no se aplican y se descuidan. Además de la información sobre los métodos de uso común, con un enfoque en MONA y la regulación en los Estados Unidos, se ofrecen observaciones y recomendaciones desde la perspectiva de un asesor que trabaja en el contexto de los Estados Unidos.

On rocks and soils, we build, maintain, and assure our lives, culture, and civilization. Every town and city, farm and ranch, commercial and manufacturing plot, and physical infrastructure and facility modifies the soils which sustain us. Of all the earth's cycles, perhaps the most important single one for our civilization is the lithologic/soil cycle. We can think of soil as the human gateway to civilization. We depend on it for vegetation, food, fiber, animal feed, wildlife, water and air quality, employment, and culture. The Food and Agricultural Organization (FAO) and The United Nations Environmental Programme (UNEP) (2021) summarize it this way in their joint report "Global Assessment of Soil Pollution" (FAO website, no date):

"Soil pollution is invisible to the human eye, but it compromises the quality of the food we eat, the water we drink, and the air we breathe and puts human and environmental health at risk. Most contaminants originate from human activities such as industrial processes and mining, poor waste management, unsustainable farming practices, accidents ranging from small chemical spills to accidents at nuclear power plants, [military facilities], and the many effects of armed conflicts. Pollution knows no borders: contaminants are spread throughout terrestrial and aquatic ecosystems and many are distributed globally by atmospheric transport. In addition, they are redistributed through the global economy by way of food and production chains.

Soil pollution has been internationally recognized as a major threat to soil health, and it affects the soil's ability to provide ecosystem services, including the production of safe and sufficient food, compromising global food security. Soil pollution hinders the achievement of many of the United Nations Sustainable Development Goals (SDGs), including those related to poverty elimination (SDG 1), zero hunger (SDG 2), and good health and well-being (SDG 3). Soil pollution hits the most vulnerable hardest, especially children and women (SDG 5). The supply of safe drinking water is threatened by the leaching of contaminants into groundwater and runoff (SDG 6). CO_2 and N_2O emissions from unsustainably managed soils accelerate climate change (SDG 13). Soil pollution contributes to land degradation and loss of terrestrial (SDG 15) and aquatic (SDG 14) biodiversity, and decreased the security and resilience of cities (SDG 11), among others."

If we look at the many ways in which soil is involved in the Sustainable Development Goals, the widespread and complex nature of soil (and soil contamination) is clear.

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Soil and its degradation

Soils are the natural dynamic product of climate, vegetation, micro-organisms, water and gases, temperature, and sometimes human and animal activity working on weathered, eroded, transported, deposited or in-place parent material over time. In coastal areas, rising sea levels contribute to soil contamination through seawater intrusion. Soils may also be manufactured and heavily manipulated in commercial agriculture, military activities, and construction and foundation works. Our once natural soils have morphed into anthropogenic soil due to intensive and extensive agricultural, industrialization, manufacturing, commercialization, and urbanization.

As in many large countries spanning several time zones and climatic and geologic regions, the U.S. contains humid as well as arid, inland and coastal regions. Where rainfall exceeds evapotranspiration (ET) for much of the year, soil leaching occurs, leading to acidic soils with an agricultural lime requirement. On the other hand, salt-affected soils are common in arid to semiarid areas, where annual rainfall is insufficient to meet plant ET needs, resulting in salt accumulation or types harmful to plant growth. This is exacerbated by high sodium- and bicarbonate- containing irrigation water as well as other potentially toxic boron, lithium, and chloride ions.

Agricultural production in the U.S. has changed remarkably over the past several hundred years. The old Native American and colonial era agronomic practices of using human wastes as fertilizers and other organic practices like the "Three Sisters" (see Box 1) are now rare, except perhaps in niche farms. European settlers brought different practices to the continent. In colonial days, American farms were largely family owned and operated on small plots using only the knowledge farmers obtained from their families, each other, and neighbors. They typically tilled or overturned the farm plots, planted and harvested cash or subsistence crops, and constituted the majority of the population. Larger farms or plantations were more common in the South based on slave or sharecropper labor. Land fallowing, manuring, manual removal of weeds, and alternative cropping with clover or legumes to renew nitrogen was common.

After the American Civil War, President Abraham Lincoln established land-grant agricultural colleges to promote teaching, research, and outreach of modern, safe, and more productive agricultural practices. Over the past 150 years or so, farms have become larger, and more commercial, effective and efficient in producing food, feed, and fiber, including for export.

The Three Sisters

According to Navajo legend, "The Three Sisters" is the combination of planted maize, squash and beans planted together in one hole. The bean vines climb up the corn stalk for support, while the squash plants cover the soil below the beans. The large leaves of the squash plants keep out the weeds and shade the soil from drying out. Although corn plants have high nitrogen demand, bean plants are legumes and remove nitrogen from the air and "fix" it in the soil, which helps meet the corn's nitrogen demand. The Three Sisters are not confined to the American southwest but are well known throughout American Indian farming practices. Of course, there are many Three Sisters stories. Here's one from Chief Louis Farmer of the Onondaga people (Great Lakes region): "In late spring, we plant the corn and beans and squash. They're not just plants. We call them The Three Sisters. We plant them together, three kinds of seeds in one hole. They want to be together with each other, just as we Indians want to be together with each other. So long as the three sisters are with us, we know we will never starve. The Creator sends them to us each year. We celebrate them now. We thank Him for the gift He gives us today and every day."). (NMSU, 2013)

Today, fewer than five percent of Americans farm, generally very productively. California, whose economy is the sixth largest in the world, produces over 30 percent of America's crops from less than three percent of its farming population. Improvements in cropping patterns (seeds), irrigation, drainage, pest and disease control (including integrated pest management where feasible), chemical fertilization, soil amendments and conditioners, automation, soil and plant scouting or monitoring and evaluation, harvesting, sorting, packaging, preservation, cold storage, marketing, and distribution account for this remarkable achievement. However, modern agriculture is not without its costs or negative impacts.

We have extensive soil pollution from pesticides, soil amendments and salts resulting from crop and plant pest and disease control and irrigated agriculture. These amendments may include not only fertilizers for organic matter and nutrients and compost for drainage, but lime and dolomite for decreasing soil acidity and sulfur and organic matter for decreasing soil alkalinity. In addition, we have a significant amount of hazardous waste pollution, such as organic solvents, from industrial and other sources.

Many of America's agricultural soils have been further degraded by wind and water erosion, nutrient losses, and destroyed structures from deep tillage. The old practices of manuring, composting, fallowing, and crop rotations which replenish commercial agricultural soils have been largely ignored in modern intensive agriculture. More commonly, these now anthropogenic or highly human-altered agricultural soils are productive largely due to application of chemical fertilizers and pesticides.

In the US, all 50 states, territories, and also foreign facilities and military bases have agricultural, industrial and manufacturing, transportation, and human settlement activities which contaminate and pollute soils. Major sources of soil pollution in the US include agricultural practices degrading soil nutrients and accumulating soil amendments, pesticides and salts; wastewaters and leachate from landfills, cemeteries, pits, ponds and lagoons; oil spills and leaking oil tanks adding petroleum and products; and military, industrial, and commercial activities contributing "priority pollutants" and other regulated hazardous substances to otherwise soils in ambient or background conditions.

In the US, the four types of common soil contaminants and pollutants are: 1. Irrigation-induced metals and farm-induced fertilizers and pesticides; 2. Industrial metals; 3. Petroleum products and volatile organics; and 4. Municipal sewage. The fate and transport of contaminants and pollutants is a fascinating study. Because soil consists largely of sand, silt, clay, organic matter, and microorganisms, dissolved metallic constituents in soil water may be attracted to and attenuated by negatively charged silt and clay particles or digested by hungry microorganisms.

The commonest or most wide-spread contaminants to soil are composed of petroleum contaminants, mainly BTEX (benzene, toluene, ethyl benzene, xylene), TPH (total petroleum hydrocarbons), TPHg (gasoline), TPHd (diesel), and fuel additives such as ethanol and MTBE (methyl tert-butyl ether). Because microorganisms in the soil approach these as food sources, they are typically naturally biodegradable under appropriate natural or enhanced conditions.

In many American coastal cities, coastal areas have been filled in with toxic dredge soil to create land from artificial fill. In San Francisco Bay, for example, dredge spoils are generally contaminated by mercury from gold mining days, hence the name Treasure Island for a prominent artificial island between San Francisco and Oakland. Moreover, Hunters Point Shipyard in southeastern San Francisco consists of over 166 hectares of serpentinite-bedrock artificial fill, containing ambient high levels of toxic metals - arsenic, beryllium, chromium, magnesium, and nickel. The Shipyard also contains significant amounts of toxic metals from using sandblast grit as trench fill. Soils and underlying groundwater have been heavily polluted by fuels and petroleum products BTEX and MTBE at both Treasure Island and Hunters Point Shipyard, as well as around many American fuel service stations (Popkin, 1999).

Soil has the ability to retain dissolved metals due to the negative charge of clay and organic matter (OM). Positively charged dissolved metal ions (cations) are attracted to the negatively charged particles which can cause them to be removed from solution and retained in the soil. Cation Exchange Capacity (CEC) or stoichiometric replacement is influenced by soil texture (higher in fine textured soil), OM content (higher in organic soil), and pH (lower in acidic soil). Soils with high CEC are able to retain a larger proportion of dissolved metals and other positively charged pollutants, while soils with low CEC will retain less (Sustainable Technologies, 2018). Exchange reactions are rapid, if the site solution is accessible, stoichiometric, reversible, and exhibits selectivity preferences among ions of different charge and size (UC Davis). See ***Box 2*** for the general ion-selectivity equation.

Selectivity exchange equations for soil

Since exchange is a chemical reaction, it can be treated like any other mass action expression and an equilibrium constant can be defined for the reaction. The equilibrium expression K has been named the selectivity coefficient, exchange coefficient and other terms.

For the reaction: $AX + B \rightleftharpoons BX + A$

We may define the following selectivity coefficient:

$$\text{Selectivity coefficient} = K^{A}_{B} = \frac{(BX)\,(A)}{(AX)\,(B)}$$

If the value of the selectivity coefficient is >1, this implies that B is preferred over A and if K<1 then A is preferred over B. There are several reasons why one ion may be more strongly attracted to the surface than another ion, such as pH, ion size and valence, and distance and orientation from soil particle surface. Source (UC Davis).

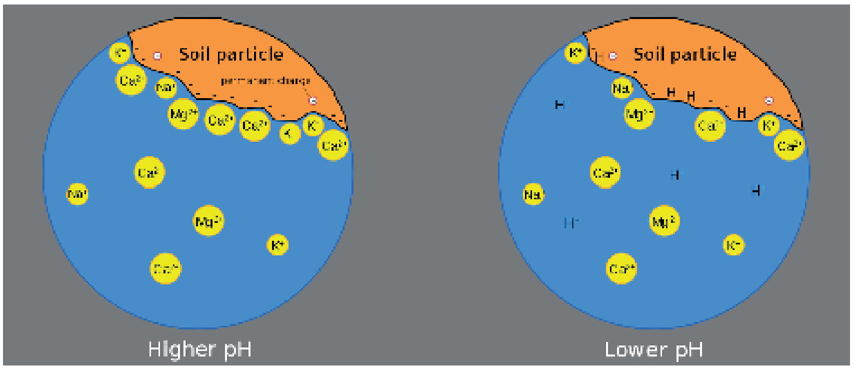


Figure 1: Illustration of CEC in high pH (acidic) and low pH (alkaline) soil particles (Sustainable Technologies, 2018. Image: Kyle MoJo & Kazem Zamanian, CC BY-SA 4.0).

Table 1: Normal range of cation exchange capacity values for common color/texture soil groups.

Soil groups	*Example US soils*	*CEC, mg/100 g*
Light colored sands	*Plainfield; Bloomfield*	*3-5*
Dark colored sands	*Maumee; Gilford*	*10-20*
Light colored loams and silt loams	*Clermont-Miami; Miami*	*10-20*
Dark colored loams and silt loams	*Sidell; Gennesee*	*15-25*
Dark colored silty clay and silt loams	*Pewamo; Hoytville*	*30-40*
Organic soils	*Carlise muck*	*50-100*

Source: Mengel, 1993

Figure 1 shows the working of cation exchange capacity in high pH (acidic) and low pH (alkaline) soil particles. The CEC of a soil sample is the sum of the exchangeable cations in the sample and is expressed in milliequivalents (meq) of positive charge per 100 grams (g) of soil. It is a measure of its ability to attenuate cations or dissolved metals in water. Low CECs (as in acidic soils) reflect low capacity of the soil to adsorb or capture cations from metals, while high CECs (found for alkaline soils) reflect the opposite. Because a soil's CEC depends on its clay and organic matter content, it can be estimated from soil texture and color. ***Table 1*** shows some soil groups, representative US soil series, and their CECs.

As the subject is so complex, there are many other additional equations for understanding soil pollution and contamination, such as: the leaching fraction, degradation and degradation products, dispersion and diffusion, dissolution and solubility, kinetics, exchange coefficients (including octanol water and fats), chelation potential, and evaporation.

Observations on Remediation

With so many different types and sources of degradation, remediation is a complex issue. Common remedial actions for major US soil pollutants are shown in ***Table 2***.

Table 2: Major US soil pollutants and common remedial actions.

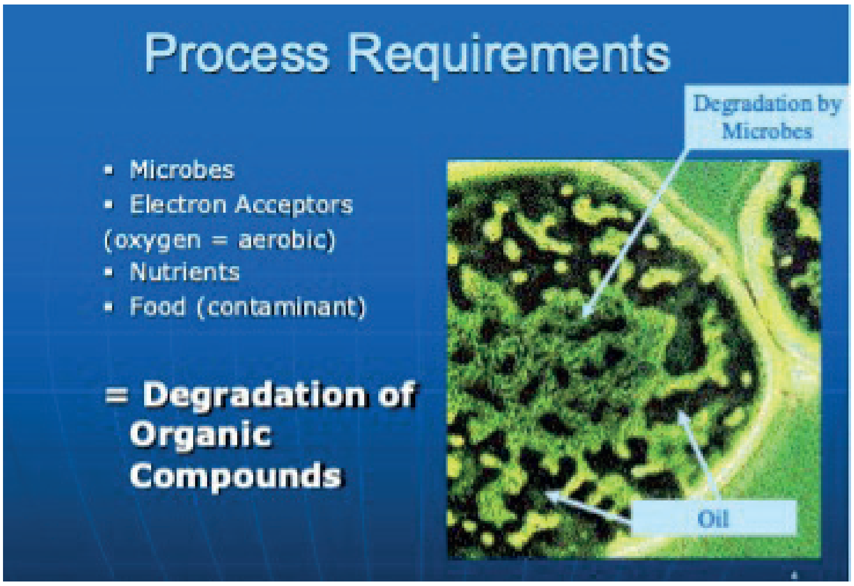
Soil Pollutant	*Common Remedial Action*	*Comments*
Dense non-aqueous phase liquids (DNAPL) and recalcitrants like methyl tert-butyl ether (MTBE)	*Containment/capsulation*	*Difficult to locate occurrence. Carcinogenic risk.*
Heavy metals (lead, mercury, zinc, cadmium, selenium, nickel, arsenic, others)	*Containment/ capsulation, in-situ fixation/precipitation/fusion, excavation/landfilling, phytoremediation/phytoextraction/ phytoaccumulation, acid washing/ leaching, electrolysis*	*Containment/capsulation often best. Hazard Index risk.*
Pesticides (includes herbicides, insecticides, and fungicides)	*Microbial degradation, phytoremediation/phytoextraction/ phytoaccumulation, containment/ capsulation, excavation/ landfilling, thermal destruction*	*Thermal destruction often best for complete treatment. Hazard Index risk for metals, otherwise carcinogenic risk.*
Petroleum products (also POL - petroleum, oil and lubricants)	*Natural attenuation, land farming of refinery wastes, aerification/aeration/ oxidation*	*Monitored natural attenuation (MONA) often best for low-risk sites. Carcinogenic risk.*
Salinity (sodium and calcium)	*Soil leaching by pre-irrigation water*	*Need to protect underlying groundwater. Irrigation risk.*
Per- and poly-fluoroalkyl substances (PFAS)	*Activated carbon, ion exchange, high-pressure membrane filtration, dissolution/ air sparging-separation*	*Carcinogenic risk.*
Sewage	*Aeration/ oxidation, leaching fields, natural degradation*	*Natural degradation (ND) often best for low-risk sites. Microbiological infection risk.*
Volatile organic compounds (VOC), polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAH)	*Soil vapor extraction, thermal destruction, aerification/ aeration/ oxidation, co-metabolic or enzyme-enriched digestion, bioengineered microorganism*	*Soil vapor extraction best when feasible. Carcinogenic risk.*

To focus on one technique, MONA – Monitored natural attenuation – is a practical strategy for remediating petroleum and other organically polluted soils and waters, where feasible (Popkin and Jacobs, 2007). In summary:

MONA is potentially an easy and effective method of hydrocarbon (HC) release cleanup, when all conditions are met. Because these conditions frequently need some enhancement, there are many ways that MONA can be optimized by adding to nature's supply of the necessary ingredients (terminal electron acceptors (TEA), nutrients, microbial colony forming units, and food). In the mid-1990s, environmental regulators recognized how natural attenuation (NA) may mitigate oil spills. NA mechanisms include evaporation or volatilization, dissolution and dilution, adsorption or sticking to soil or aquifer surfaces, intrinsic biodegradation or consumption by micro-organisms, and product aging or transformation. MONA is now the presumptive cleanup remedy for petroleum releases in which the various parameters are verified and documented in guidance documents and case studies prepared by the AFCEE, USGS, and USEPA.

Visualizing the subsurface as a giant biofilter treatment system, MONA is demonstrated through contaminant mass reduction (difficult to show), and more easily, the presence of micro-organisms, reduction in contaminant concentrations, HC conversion to byproducts, and environmental attenuation markers. Where microbes, food source (hydrocarbon, HC), macronutrients and terminal electron acceptors are plentiful, microbial degradation proceeds unimpeded. For aerobic (O_2) HC degradation, dissolved oxygen (DO) must be at 1 to 2 mg/L. At many sites, DO is consumed rapidly in the core of the plume shortly after the HC release, followed by consumption of other TEAs in the order of decreasing metabolic rates: NO_3, Fe(II)/ Mn, SO_4, and CO_2. If these TEAs were abundant in nature, long HC plumes would not develop. The energy level for aerobic microbes is much higher than the others; they are more efficient eaters of HC. Once O_2 and NO_3 are consumed, meaningful HC degradation stops. Conditions may be enhanced by passively adding DO or macronutrients. MONA cleanups are so well defined that they are often contracted under pay-for-performance agreements.

Figure 2 illustrates the process requirements for MONA. This technology has been successfully applied to remediate MTBE, chlorinated solvent, perchlorate, nitrate, solvent stabilizers, petroleum hydrocarbons, polychlorinated biphenyls (PCB), pesticides, and other organic pollutants in soils and groundwater in the US. Routine non-monitored natural attenuation occurs US-wide for many contaminates and pol-



Process Requirements

- Microbes
- Electron Acceptors
(oxygen = aerobic)
- Nutrients
- Food (contaminant)

= **Degradation of Organic Compounds**

Figure 2: Process requirements for MONA (Source: Popkin and Jacobs, 2007).

lutions, such as from irrigation fields, cemeteries, underground storage tanks, oil and gas refineries (ex. land farming), landfills, septic tanks, sewage leaching fields, and leaking wastewater collection pipelines. There is a good reason why its common practice to burry wastewater sewer lines below water lines and to place septic tanks over 33 meters from water wells, rivers or springs. In the US, sewage-polluted soils are not remediated by being left alone to naturally biodegrade. As most of the US has sewage systems in urban areas or contains septic tanks in rural areas, and leakage accounts for perhaps 10 to 25% of sewage flows, the amount of sewage leaking into soils is significant (Tchobanoglous and Keith, 2002; Tchobanoglous *et al.*, 2003).

Petroleum and volatile organic pollutants (VOC) in soil may be removed by natural monitored attenuation (MONA) through ambient resident or introduced bacteria which can be enhanced by oxygenation, enzymes, or co-metabolic food-source additions like wastewater sludge, dissolved fructose, sugar, or molasses. These petroleum and VOC soil pollutants are common wherever petroleum is produced, stored, used, or disposed (Tetra Tech EMI, 1998; Popkin and Jacobs, 2007).

Heavy metals in polluted soils are removed by soil excavation, plant extraction and landfill burial, heavily acidified leaching waters, or electrical-current concentration and seepage removal, but may also be solidified in soil by in-place thermal fusion. These industrial-metals soil pollutants are common at active and abandoned industrial, fabrication, and landfill sites (Bohn *et al.*, 2001).

For metallic, embalming fluids, nuclear materials, pesticides, medicinals, dense non-aqueous phase liquids (DNAPL), per- and poly-fluoroalkyl substances (PFAS), resins, recalcitrants, and other pollutants, more aggressive technical treatments are needed. To treat such pollutants more research and development is needed though genetically modified and adapted organisms.

The irrigation-introduced accumulated soil metals calcium, magnesium, sodium, potassium, selenium and boron are removed from farmed soil by pre-season irrigation leaching, requiring as much as 10 to 30% of irrigation water demand. The process can be enhanced by acidifying the leaching water with dissolved sulfur powder, gypsum or manure. These irrigation-metal soil contaminants are common in dry land soils west of the Mississippi River to the Pacific Ocean (Ayers and Westcot, 1976; US Salinity Laboratory, 1954).

Our polluted soils from agricultural processes such as crop pest and disease control and irrigation farming can be reduced by integrated pest management strategies, minimum irrigation practices, and soil-salt leaching management strategies. Managing accumulated salt in soils is usually accomplished by leaching or pre-irrigation, which requires more fresh water and may increase weeds, or by leachate extraction wells and disposal to streams or less commonly to deep aquifers and abandoned mines. These are well documented in the professional literature.

Environmental laws and regulation in the US

The United States has extensive environmental laws and regulations at all levels of government which protect human health and the environment, including soil. In general, the US is a heavily environmentally regulated country, although there is a long-term permanent shortage of inspectors and regulators willing and able to enforce our scores of federal and many more local regulations, laws, and local codes and ordinances. The environmental protection principles of “command and control” and “let the polluter pay” (Schmidheiny, 1992) are well established and known but often not strictly implemented. This is especially true when applied to major or dominant businesses, government itself, the military, American Indian Native Tribes (which are “sovereign nations”), and favored industries like agriculture, mining, and oil and gas.

US federal laws are extensive in protecting human health and the environment, including soils. The major federal environmental acts are The federal Antiquities (1906), Oil Pollution (1924 & 1990), Federal Insecticide Fungicide and Rodenticide (1947), Federal Water Pollution Control (aka Clean Water Act, 1948), Clean Air (1963), Solid Waste Disposal (1965), National Historic Preservation (1966), Occupational Health and Safety (1970), National Environmental Quality (1970), Resource Conservation and Recovery (1970), Endangered Species (1973), Toxic Substances Control (1976), Comprehensive Environmental Response Compensation and Liability (1980), Asbestos Hazard and Response (1986), and Emergency Planning and Community Right-to-Know (1986) acts as amended.

US Federal Environmental Statutes tend to be command-and-control prescriptive statutes and make-the-polluter-pay statutes, with a few informational statutes for decision-makers (e.g. NEPA, CEQA). They have been passed by the US Congress, and pertain to (a) regulation of the interaction of humans and the natural environment, or (b) conservation and/or management of natural or historic resources. They need not be codified in the U.S. Code of Federal Regulations. In addition, there are others regulations, plus amendments, updates, revisions, administrative rules, legal decisions and common compliance practices. Most states and tribes have adopted federal laws and have primacy to implement them, while some state laws are more stringent than federal law.

The US Environmental Protection Agency (USEPA or EPA; see Box 3 for a list of acronyms) is the presumptive national environmental authority. These

Useful acronyms: Acts, agencies, and other organizations

AFCEE	*Air Force Center for Engineering and the Environment*	*NOAA*	*National Oceanic and Atmospheric Administration*
CEQA	*California Environmental Quality Act*	*NRC*	*Nuclear Regulatory Commission*
CWA	*Clean Water Act*	*OHSA*	*Occupational Health and Safety Administration*
EA	*environmental assessment*	*POTW*	*publically owned treatment works*
EIS	*environmental impact statement*	*RCRA*	*Resource Conservation and Recovery Act*
EPA, USEPA	*US Environmental Protection Agency*	*ROD*	*record of decision*
FONSI	*Finding of No Significant Impact*	*USACE*	*U.S. Army Corps of Engineers*
MOU	*Memorandum of Understanding*	*USDA*	*US Department of Agriculture*
NEPA	*National Environmental Policy Act*	*USGS*	*US Geological Survey*

federal acts are administered primarily by the US Environmental Protection Agency (USEPA) along with the Department of Justice, and state agencies where promulgated. Other agencies include the Occupational Health and Safety Administration (OHSA), the President's Council on Environmental Quality for NEPA, USACE for inland waters, NOAA for coastal waters, USDA (Forest Service) for national forests, National Park Service, Forest Service, Fish and Wildlife Service, and/or the Bureau of Land Management for national monuments, Bureau of Indian Affairs for Indian Lands, NRC for radioactive wastes, MOUs (ex. mixed low-level radiation and hazardous waste; military facilities. The Administrative Procedures Act establishes the process by which federal agencies make regulations and the process by which citizens can challenge those decisions.

Some states, such as California, have stricter environmental regulations, such as the California Environmental Quality Act (1970) and the posted warnings and bounty provisions of California Proposition 85 (1986). Moreover, judges may interpret US law in new ways, thus defining new initiatives such as "environmental justice."). Administrative and other courts may become involved as legal venues for relief through administrative and other courts if people filing a lawsuit can demonstrate that they have a stake in the outcome.

The government itself passed a law for its work abroad (22CRF216) for environmental protection as a result of a lawsuit over several inadvertent pesticide-related deaths; however, it is not enforced in practice as there is little or no public interest in litigating it and the US Agency for International Development Automated Directive System has no mandated penalties for non-compliance.

Observations on issues involving regulation

These challenges are illustrated below in examples of federal, state, county, and municipal issues, based in part by my observations and research, including Popkin (2015, 2017). I hope that this section gives a glimpse into the complex interaction of various regulations, the interests of companies, and the public interest. In all cases, the legal and regulatory requirements do not have significant impact on environmental behavior without enforcement, public pressure, and significant consequences for non-compliance.

As a general guide to procedures, the National Environmental Policy Act (NEPA) requires that when the federal government has authority to grant or deny a permit for a proposed activity, or federal land and waters are involved, the government must review the proposal and reach a Finding of No Significant Impact (FONSI) or may order an environmental assessment (EA) or a more comprehensive environmental impact statement (EIS) with stakeholder, beneficiary and public consultants. Finally, a record of decision (ROD) is issued. Often NEPA's EIS process is used as a delaying tactic to give project objectors time to prepare a litigation case. The outcome is only advisory, without necessarily killing a proposed activity, especially if there are broad social or economic benefits and potential adverse effects may be mitigated. Several states have stricter equivalents: California's version, which preceded NEPA, requires that a court may kill a project from going forward if the court decides the project would not be in the public interest.

Example 1. In California, there was a request for a state permit under state law to expand an ongoing hazardous waste landfill. This required informed consent of the residents in that area. Waste Management's consultant placed public notices, held public meetings for scoping, wrote the EIR and presented it to a public meeting. Unfortunately, hardly anyone read the notices or participated in the scoping or any of the meetings, in Kings County, where the landfill was operated. By chance the very famous environmental activist Ellen Brockovich (no doubt you loved the movie made about her with Julia Roberts – all true by the way) saw a meeting notice and joined with a well-known environmental activist organization to sue the project proponent. They were right! Although the federal and state laws require postings, notices, meetings, etc., *they do not specify the language.* Posting in English ONLY may not be effective to inform a community which largely isn't English-speaking and so can't get the information needed for informed consent. Most residents of Kings County were Spanish-only speakers, listening to Spanish language radio, watching Spanish-language TV, seeing Spanish-language movies, and reading Spanish-language newspapers. The judge ruled against the project proponent and required recasting everything including the process in Spanish. The proponent declined to pursue it, as everyone in the county hated the project from then on. Oh, and the judge coined a new phrase, *environmental justice.*

Example 2. There was a Resource Conservation and Recovery Act (RCRA) hazardous waste site adjacent to the Houston Ship Channel tunnel (Houston, Texas), which was an active oil refinery. The state closed the channel due to noxious odors. By chance, environmental technicians saw a machine shop worker unlock a monitoring well and pour shop wastes down the well. The worker said the shop foreman's policy was to routinely dispose of shop wastes down these holes as it was cheaper than disposal to RCRA-certified treatment, storage and disposal facilities, which required a licensed hauler and facility and tons of paperwork.

Example 3. The CWA upgraded its standards for effluent releases from publicly owned treatment works (POTWs) and required the states to pay for these federally mandated, and often state enforced requirements, which then ordered their municipalities to pay. President Reagan ended the federal funding to upgrade POTWs. The Arizona Department of Environmental Quality required Pima County to meet these standards. This is how Pima County had to take a loan of over $200 million, not including cost-overruns and debt service, to upgrade its regional wastewater reclamation facilities or POTWs to meet the requirements so that the effluent would not harm aquatic life in the receiving national waters of the US. Do you think there are such receiving waters in or near Pima? Nutrient removal is very costly, but there's a hidden benefit: our nutrient-free wastewater is a great fresh drinking water source recharging our aquifers. The Pima County sewer service rates are largely due to debt service on nutrient removal of nitrogen and phosphorus.

Example 4. San Francisco citizens organized to draft an Environmental Baseline Report and then an Environmental Action Plan. They lobbied the Board of Supervisors to create an Environmental Department to promote environmentally sound management. To meet rising city water and wastewater capital and operation and maintenance costs, the city raised water and sewer rates significantly each year. Even though the City provided rate subsidies to the poor, many poor people were too proud, uninformed about or disinterested in applying for these generous subsidies. Many of the families installed their own shallow drinking water wells with well points and fitted them with air compressors as pumps to avoid paying the city's water and sewer fees. This was both illegal and unhealthy, as the artificial fill materials in the shallow aquifer were mainly composed of old landfills, slaughterhouse wastes, commercial and industrial wastes, and oil spills. Several human health studies confirmed high levels of asthma, diabetes, hypertension, and several forms of cancer in the neighborhood. Because there were high levels of smoking, alcoholism, red meat consumption, obesity, crime and social stress, drug use, incarceration, and amateur home repairs and gardening, as well as exposure to contaminated drinking water, the studies were unable to separate the causes. But this situation led to the city establishing several neighborhood health clinics.

Example 5. RCRA Class I Landfills for hazardous waste are required to have a three-foot thick clay liner beneath the landfill to protect underlying groundwater from landfill leachate. The RCRA writers assumed that a foot of compacted clay would be impermeable to water and certainly three feet would be even better. However, a Rice University professor and colleague of mine discovered by laboratory and field tests that several carcinogenic VOCs like TCE would readily flow through any thickness of clay liners. After much debate, the EPA then required leachate collection systems to be installed in the liners – with debatable results.

Example 6. People learned that it was possible to get around the EPA standards for effluent releases from POTWs if triplicate and reproducible lethal dose laboratory tests (LD50) on specified laboratory-bred fish using effluent provided by the POTW were within acceptable limits. This created a great laboratory business for decades, yet many tests were inconclusive and some even showed that drinking water killed more fish than polluted water! I suspect this is because the "drinking water" used in those tests contained chlorine as a residual disinfectant.

Observations on Regulations and Science

Sometimes science conflicts with regulation. Regulations need to be clear, simple, and enforceable, while pollution can be very complex.

For instance, to enforce water quality standards for wastewater effluent, and more recently for non-point pollution sources, from say parking lots and streets, the standards are typically a single number for each chemical. But chemicals often have several forms. For instance, dissolved arsenic, iron, and chromium have several charges or valances, where some are deadly and others are required human health nutrients. In addition, there is a vast difference if the metal contaminant is a solid mass or in a dissolved solution which can enter your blood stream. All the iron, chromium, copper, nickel, etc. in the coins, watches, jewelry, and piercings that we are exposed to all day cannot readily get into our blood stream, even if they appeared in a laboratory analysis, so it would be patently silly to count these in a laboratory analysis to meet the regulated standard.

Most dissolved metals are highly attracted to clay particles of any and all sizes. Plus, many metals are within the mineral matrix physically embedded within soil or sediment, unavailable to life forms. The colorful chrome, nickel, cadmium, lithium, etc. in silica which make it into gemstones like amethyst, emerald, garnet, sapphire, lapis, turquoise, etc. are not dissolved in your blood stream, so they shouldn't count. Finally, due to medical and pharmaceutical research and drug production, there is an enormous amount of anthropogenic or man-made, benign chelating agents which tie up metals, making them biologically unavailable in the southern San Francisco Bay waters.

It would be a nightmare to convince regulators to exclude metals in all such forms, species or states for a one-book number regulation standard. Consequently, treating wastewater or contaminated soil to meet such standards is extremely "conservative" or "overly protective" and enormously costly.

Conclusions and Recommendations

Modern commercial farming requires the use of fertilizers, pesticides, and soil amendments to meet the growing demands for food, animal feed, and fiber. In the US this is especially true in the nutrient-poor soils of the dry western states and the pest-rich moist and humid eastern states. It is impossible to imagine a modern world free of industrial hazardous materials and wastes related to manufacturing and other activities. It is naïve to visualize a modern world free of petroleum and volatile compounds to support industry and energy. It is impractical to envision a modern world without sewage collection, treatment, and disposal to support human and ecological health.

Our polluted soils contribute to the degradation of our agriculture, wildlife, recreation, water and air quality, public health, and environment. Legislation and regulations are intended to minimize these effects. However, the legal and regulatory requirements will not have a significant impact on environmental behavior without enforcement, public pressure, and significant consequences including penalty fees and prison terms for non-compliance. It is unlikely that those who pollute our soils will be persuaded to mitigate their pollution by incentives.

We know that it is possible to protect our soils – proper regulation and enforcement are both important, but other goals also motivate action. Likely the most fiercely nurtured soils, and those best protected from these forms of soil degradation, are the soils which are used to produce high quality wines from identified American Viticulture Areas and other wine-producing areas. Soil is also carefully protected at landmark monuments, sites that are historically significant, recreational and sporting event sites, golf courses, and other selected locations. The commercial value of golf courses in the US is enormous. Organic farmers are paying close attention to the quality of the soil and experimenting with methods for improving it. Perhaps a return to some Native American farming practices could be encouraged, at least in small-scale farming.

Beyond 'command-and-control' and 'make-the-polluter pay' strategies, there is budding evidence that behavioral changes are feasible for enhancing environmentally sound soil management. However, these changes are likely realized only through targeted, ongoing incentive campaigns which would appeal to behavioral motivational instincts. Increased regulatory enforcement and public pressure are needed to make improvements in managing polluted soils in the US. These will be costly and make many people unhappy.

Whether or not anything that humans may achieve or attempt as "sustainable" is dubious and debatable. But most of us may agree that environmentally sound management of our natural resources, including soil, is wise. As noted by my late University of Arizona soil chemistry professor, Dr. Hinrich L. Bohn (Bohn *et al.*, 2001, p. xi):

1. All the chemical elements – toxic and beneficial – were always in the soil;
2. The soil is the safest part of the environment in which to deposit our wastes;
3. There are wise and unwise ways to utilize soil for waste disposal;
4. Soil chemistry degrades wastes and converts them into benign or useful substances;

5. Environmental activists and the popular media usually ignore the dose-response concept that is central to toxicology and to soil fertility; and
6. How much is in the soil, how fast it is changing, and how easily it transfers to plants and water are more important than what is there.

More work needs to be undertaken and refined on soil, water, and air pollutant fate and transport, degradation products, toxicity to demographically defined people and plants and animals, combined chemical impacts of hazardous materials, risks and uncertainties, and remediation (including bioengineering) by hydrologists, toxicologists, epidemiologists, risk assessors, biochemical engineers and scientists, and statisticians. Much relevant work in the US is performed and published primarily by the USEPA, the US Air Force, USACE, USDA, USGS, and many universities and specialty research centers.

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News corner:
Compiled by Anita Stein, EFG Office

Partnership with the Earth Futures Festival

Earth Science, or geoscience, is the keystone to understanding the complex and changing relationships between the planet's physical and biological systems, and human interaction with the environment and climatic impacts. Yet despite the critical role geoscience plays in building our sustainable future, the discipline is under threat. Current public perception, limited mass-media coverage, declining university student numbers, university degree programme cuts and loss of academic expertise in geoscience are leading us towards a future shortage of knowledge and skills. This will limit humankind's ability to deliver solutions in managing the sustainable future use of the planet and mitigation of natural hazards, with costly economic, social and environmental consequences.

To raise awareness of the crucial role geoscience plays in leading us on a path to a more sustainable future, award-winning geoscientist Dr. Heather Handley and TV Executive Producer Simon John Heath have teamed up with the UNESCO International Geosciences Program and the International Union of Geosciences to establish the Earth Futures Festival. The Festival is supported by Patron Iain Stewart, Professor of Geoscience Communication and UNESCO Chair in Geoscience for Society.

The Earth Futures Festival is an international film and video festival showcasing the important role geoscience plays in addressing our most pressing sustainability challenges. The finalist videos will be shown online throughout September and October 2022 with in-person screening and panel discussion events in New York City, Paris and Sydney, all culminating in an awards event in Sydney.

Equity, diversity and inclusion are central to the project. The festival will encourage, support and recognise diverse voices through a number of grants for those with limited access to technical equipment, carefully selected submission categories, education and training in storytelling, editing and film-making, and awards designed to celebrate diverse teams and content.
The Festival is calling for professionals and students in the realms of geoscience, the arts and science communication along with community groups, associations, school students and First Nations peoples to submit 90-second to 90-minute works in video format. This year's themes are Dynamic Earth, Future Earth and Human Connection. Submissions open on 1 February 2022 and close on 15 May 2022.

To find out more about the Earth Futures Festival please go to ***https://www.earthfuturesfestival.com***

The European Federation of Geologists is proud to support the Earth Futures Festival as a partner organisation.

EU projects

Horizon 2020 is the biggest EU research and innovation programme ever, with nearly €80 billion of funding available to secure Europe's global competitiveness in the period 2014–2020. EFG is currently involved in four active Horizon 2020 projects: ROBOMINERS, CROWDTHERMAL, REFLECT and SUMEX. In addition, EFG is also participating in two projects under the EIT RawMaterials initiative: ENGIE and PROSKILL. Below you will find descriptions of the topics and aims of these projects.

ROBOMINERS

ROBOMINERS

820971 – ROBOMINERS
Resilient Bio-inspired Modular Robotic Miners
START DATE: 1 June 2019
DURATION: 48 months
http://robominers.eu

Objectives:

ROBOMINERS will develop a bio-inspired, modular and reconfigurable robot-miner for small and difficult-to-access deposits. The aim is to create a prototype robot that is capable of mining underground, underwater or above water, and can be delivered in modules to the deposit via a large diameter borehole. In the envisioned ROBOMINERS technology line, mining will take place underground, underwater in a flooded environment. A large diameter borehole is drilled from the surface to the mineral deposit. A modular mining machine is delivered in modules via the borehole. This will then self-assemble and begin its operation. Powered by a water hydraulic drivetrain and artificial muscles, the robot will have high power density and environmentally safe operation. Situational awareness and sensing is provided by novel body sensors, including artificial whiskers, that will merge data in real-time with production sensors, optimising the rate of production and selection between different production methods. The produced high-grade mineral slurry is pumped to the surface, where it will be processed. The waste slurry could then be returned to the mine where to backfill mined-out areas.

ROBOMINERS will deliver proof of concept (TRL-4) of the feasibility of this technology line that can enable the EU have access to mineral raw materials from otherwise inaccessible or uneconomical domestic sources. This proof of concept will be delivered in the format of a new amphibious robot Miner Prototype that will be designed and constructed as a result of merging technologies from advanced robotics, mechatronics and mining engineering. Laboratory experiments will confirm the Miner's key functions, such as modularity, configurability, selective mining ability and resilience under a range of operating scenarios. The Prototype Miner will then be used to study and advance future research challenges concerning scalability, swarming behaviour and operation in harsh environments.

REFLECT

850626 - Redefining geothermal fluid properties at extreme conditions to optimize future geothermal energy extraction
START DATE: 1 January 2020
DURATION: 36 months
https://www.reflect-h2020.eu/

Objectives:

The efficiency of geothermal utilisation depends heavily upon the behaviour of the fluids that transfer heat between the geosphere and the engineered components of a power plant. Chemical or physical processes such as precipitation, corrosion, or degassing occur as pressure and temperature change, with serious consequences for power plant operations and project economics. Currently, there are no standard solutions for operators to deal with these challenges. The aim of REFLECT is to avoid the problems related to fluid chemistry rather than treat them. This requires accurate predictions and thus a thorough knowledge of the physical and chemical properties of the fluids throughout the geothermal loop. These properties are often only poorly defined, as in situ sampling and measurements at extreme conditions are hardly possible to date. As a consequence, large uncertainties prevail in current model predictions, which will be tackled in REFLECT by collecting new, high quality data in critical areas. The proposed approach includes advanced fluid sampling techniques, the measurement of fluid properties in in-situ conditions, and the exact determination of key parameters controlling precipitation and corrosion processes. The sampled fluids and measured fluid properties cover a large range of salinity and temperature, including those from enhanced and super-hot geothermal systems. The data obtained will be implemented in a European geothermal fluid atlas and in predictive models that both ultimately allow operational conditions and power plant layout to be adjusted to prevent unwanted reactions before they occur. That way, recommendations can be derived on how to best operate geothermal systems for sustainable and reliable electricity generation, advancing from an experience-based to a knowledge-based approach.

ENGIE

Encouraging Girls to Study Geosciences and Engineering
START DATE: 1 January 2020
DURATION: 36 months
https://www.engieproject.eu/

Objectives:

ENGIE aims to turn the interest of 13-to-18-year-old girls towards studying geosciences and related engineering disciplines. As career decisions are generally made in this period of life, the project aims to improve the gender balance in the fields of these disciplines. During the implementation of the three-year-long project an awareness-raising strategy will be developed and an international stakeholder collaboration network will be established for the realisation of a set of concrete actions. These actions include family science events, outdoor programmes, school science clubs, mine visits, mentoring programmes, international student conferences, competitions, publication opportunities, summer courses for science teachers and production of educational materials. The actions will be carried out in more than twenty countries throughout Europe.

PROSKILL

Development of a Skill Ecosystem in the Visegrád Four countries
START DATE: 1 January 2020
DURATION: 36 months
www.proskillproject.eu

Objectives:

The European Union puts emphasis on raising productivity as an important factor in maintaining economic growth. In order to improve productivity, it is vital to offer products and services with a high added value, and for that purpose highly qualified employees are required. Companies and professional organisations in the raw materials industries have stressed the need to improve the soft skills of students in order to meet the requirements of the labour market. The engineers of the future have to accept that engineering problems – as well as their solutions – are embedded in complex social, cultural, political, environmental and economic contexts. Engineers have to access, understand, evaluate, synthesise, and apply information and knowledge from engineering as well as from other fields of study. They have to find and achieve a synergy between technical and social systems. ProSkill has a double purpose. From the one side it adopts a 'skill ecosystem' concept, looking at what (hard and soft) skills are missing in the raw materials sector, which areas are affected by skill problems (shortages, mismatches and gaps) and what strategies can work. A high-skill ecosystem strategy supplemented with an action plan is developed. To ensure sustainability, the project focuses on lecturers in higher education ('train the trainer'). The main goal is to develop their knowledge about new and innovative educational techniques and to reshape outdated curricula. On the other side, a pilot project is launched involving the colleges for advanced studies in partner HEIs. Short-term and long-term programmes help to implement the strategy with the targeted development of selected soft skills.

SUMEX

101003622 - SUstainable Management in EXtractive industries
START DATE: 1 November 2020
DURATION: 36 months
https://www.sumexproject.eu/

Objectives:

SUMEX is a 36-month project funded by the European Commission that started on 1 November 2020. The project supports the set-up of a European sustainability framework to improve the permitting procedure along the extractive value chain (prospecting, exploration, extraction, processing, closure, post-closure activities), to guarantee timely decisions, a transparent governmental regulatory regime, appealing financial and administrative conditions and sustainable natural environmental and social conditions. The main mission of SUMEX is to assist policymakers and other stakeholders in seizing this opportunity.

In order to foster more extensive but sustainable mineral production in the EU, SUMEX (SUstainable Management in EXtractive industries) will establish a sustainability framework for the extractive industry in Europe. It does so by considering the Sustainable Development Goals, the European Green Deal, as well as EU Social License to Operate considerations and will involve stakeholders from industry, government, academia and civil society backgrounds from all across the EU.

CROWDTHERMAL

857830 – CROWDTHERMAL Community-based development schemes for geothermal energy
START DATE: 1 September 2019
DURATION: 36 months
http://crowdthermalproject.eu

Objectives:

CROWDTHERMAL aims to empower the European public to directly participate in the development of geothermal projects with the help of alternative financing schemes (crowdfunding) and social engagement tools. In order to reach this goal, the project will first increase the transparency of geothermal projects and technologies by creating one-to-one links between geothermal actors and the public so that a Social Licence to Operate (SLO) could be obtained. This will be done by assessing the nature of public concerns for the different types of geothermal technologies, considering deep and shallow geothermal installations separately, as well as various hybrid and emerging technology solutions. CROWDTHERMAL will create a social acceptance model for geothermal energy that will be used as baseline in subsequent actions for inspiring public support for geothermal energy. Parallel and synergetic with this, the project will work out details of alternative financing and risk mitigation options covering the different types of geothermal resources and various socio-geographical settings. The models will be developed and validated with the help of three case studies in Iceland, Hungary and Spain and with the help of a Trans-European survey conducted by EFG Third Parties. Based on this feedback, a developers' toolbox will be created with the aim of promoting new geothermal projects in Europe supported by new forms of financing and investment risk mitigation schemes that will be designed to work hand in hand with current engineering and microeconomic best practices and conventional financial instruments.

European Geologist indexed in DOAJ

Since July 2021, the *European Geologist* journal is indexed in the Directory of Open Access Journals (DOAJ, ***https://doaj.org/***). The DOAJ is an independent database containing over 16,500 peer-reviewed open-access journals covering a broad range of science disciplines. DOAJ's mission is to increase the visibility, accessibility, reputation, usage and impact of peer-reviewed, open-access scholarly research journals. DOAJ is committed to being fully independent and offering its primary services and metadata as free to use or reuse for everyone.

This represents a major step for the European Geologist journal and reflects EFG's intention to continuously raise the standards of its peer-reviewed Diamond Open Access publication.

Winners: photo contest 2021

EFG and EAGE are pleased to announce the winners of the 2021 edition of the "Legends of Geoscience" Photo Contest.

We have received many inspiring pictures submitted in the three categories Geosciences for Society, Women Geoscientists and Landscape and Environment. Many thanks to all participants for sharing your passion for geosciences with us. Thanks also to the public who participated in the polls which allowed us to determine the winners of this edition.

We are glad to introduce the three winners of this year's contest here below.

Discover the 12 finalists of the 2021 contest at ***https://bit.ly/377dLpA***

First prize:
"Sometimes it Takes a Woman to Find the Real Fault" by Dharti Patel

"The photo was taken in Kutch, Gujarat, India on a geological field study. Our class traversed towards the south and headed west after a while. I stressed upon a traverse detour further to the south which led our team to this beautiful outcrop (~6 m tall) with a magnificent fault that would have otherwise gone undiscovered. Hence came the title."

Second prize:
"Drawing of a complicated artwork" by Mehrangiz Naderi Khujin

"We were 14 geologists on a 5-day geological field trip in January 2020 in the Bandar Abbass area, south of Iran, for visiting Cretaceous and Cenozoic formations of Zagros Mountain. That was our last geological program before the Covid-19 pandemic. After passing a wonderful canyon, we were standing near that nice rock wall. We began to draw and interpret the sequence stratigraphy units and surfaces of that complicated rock wall (Jahrom Formation). Silence, coolness and beautiful scenes of the canyon will be always in my mind."

Third prize:
"Landslide" by Giorgi Lomidze

"This picture was taken in Svaneti, Georgia."

EFG contributed to FAO report on soil pollution

On 4 June 2021, the Food and Agriculture Organization (FAO) of the United Nations released its report "Global Assessment of Soil Pollution", which addresses the extent and future trends of soil pollution and describes the risks and impacts of soil pollution on health, the environment and food security. Over the last three years, EFG has actively supported the preparation of this state-of-the-art report through the involvement of its External Relations Officer, Dr Pavlos Tyrologou, a member of the EFG board and the Panel of Experts on Soil Protection.

"Over the recent decades, the Earth's population has been steadily rising, creating pressures both in the food supply (expected increase 70–100% by 2050). Degraded land covers ~24 % of the global land area, with financial and ecological costs for their restoration being transferred to future generations. The legacy of intensive industrial activity (including agricultural) has inevitably created a vast amount of depleted and derelict land areas. Soil contamination has a direct impact on the United Nations Sustainable Development Goals (SDGs), especially on poverty elimination (SDG 1), zero hunger (SDG 2), good health and well-being (SDG 3) as well as the supply of safe drinking water, where the leaching of contaminants into groundwater and runoff can degrade its quality (SDG 6)." (Pavlos Tyrologou)

The process to develop the report involved in-depth regional assessments of soil pollution, and the regional chapters provide an overview of soil pollution issues at a global scale. The Editorial Board comprised more than 30 international experts. In this context, EFG co-authored Chapter 13 of the report and participated in the external reviewers' team.

The report can be accessed at ***http://www.fao.org/documents/card/en/c/cb4894en.***

How can geologists help to prevent, monitor and tackle soil pollution?

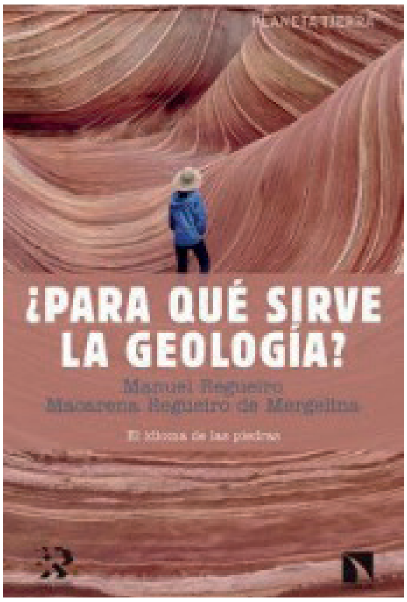
"Geologists with their diverse background in geochemistry, hydrogeology, engineering geology, including mineralogy, among others, can provide their support to better understand earth processes and how these can be affected by anthropogenic activities and have an impact on the soil quality.
Geologists working with other soil-related disciplines can be part of the solution for securing the natural soil asset for the current and future generations, making sure of an equal access by everyone and making sure that no one is left behind.
We were honoured to be part of the process, and we are looking forward to providing our support to similar activities to our society's benefit."

Pavlos Tyrologou, EFG External Relations Officer and member of the Panel of Experts on Soil Protection

Book review by Juan José Durán Valsero, Geologist

What is Geology For? (¿Para qué sirve la geología?)

By Manuel Regueiro Gonzalez-Barros and
Macarena Regueiro de Margelina.
2019. Editorial Catarata, Madrid, 141 pp.
Edición de papel. P.V.P 12€.
https://www.casadellibro.com/libro-para-que-sirve-la-geologia/9788490976944/9616590



"The Language of Stones" is the subtitle chosen by the authors for this outreach book published by the Catarata Publishing Company and the Geological Survey of Spain.

In fourteen chapters and 144 pages the authors explain in detail a series of specialties of geology, starting with Paleontology and finishing with Astrogeology, describing also Geological Mapping, Geological Hazards, Hydrogeology, Mineral Resources, Hydrocarbons, Marine Geology, Geochemistry, Geophysics, and Geomorphology, as well as academia and research, understanding the last as an activity carried out by geologists as opposed to a branch of geology.

Up to here, this would be the review of a normal book, as many other, dedicated to geological sciences. But in this case we are presented with some very particular characteristics. The first one is that the authors are father and daughter. The father is an experienced geologist, almost at the end of his professional career, Chief of External Affairs and Communication of the Geological Survey of Spain (IGME), who has spent his professional life in many different fields of geology. The daughter represents a complete counterpoint: actress, poet, theater director, she does not have the usual profile for this genre.

Maybe because of that, the content of the book is far from usual. The structure of each chapter is repeated, including always a relatively short part with technical content, dedicated to explain the geological specialty described in the chapter (that is, what is geological mapping, what is its use, how is it done, etc. in the case of the first chapter) and then another part, the most original, in which readers are presented in the form of a short story, featuring fictional but true-to-life geologists that illustrates in a very graphic and simple way the real everyday life of geologists.

Very probably, once the book is finished, even readers not related to the geological world will get a better idea of what geologists do and what is the use of what they do.

For the reader closer to the geological world, (or even inside that world) the book will be enjoyable, remind you of some past situations and maybe even reveal uses of geology that you might not know.

In any case, reading this book is highly recommended, as not every day we find such an out-of-the ordinary book in the publishing scene.

Book review by EurGeol Gareth Ll. Jones PGeo,
Past President of the European Federation of Geologists and of the Institute of Geologists of Ireland

Mentoring Scientists and Engineers: The Essential Skills, Principles and Processes

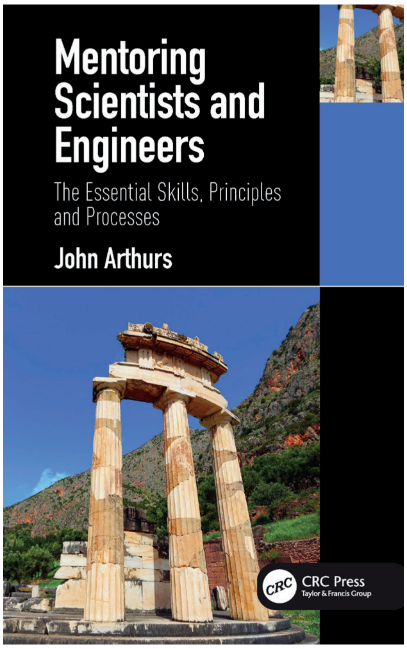
By EurGeol John Arthurs PGeo
CRC Press, 2021
ISBN13: 9780367724009 (pbk)
Paperback English ~€40.78
Also available in Hardback ~€103.72
A 20% discount on the full UK pound sterling price of £34.99 is available on the publisher's website: ***www.routledge.com/9780367724009***
Just enter the code FLY21 at the checkout. Both Hardback and eBook versions are also available. Note that the discount does not apply to the eBook, which is already at the equivalent discounted price of the paperback.
Should you like to contact John directly you can do so via: ***jwarthurs@ntlworld.com*** or ***linkedin.com/in/john-arthurs***

My old friend and colleague EurGeol John Arthurs PGeo has followed up on his well-received and popular mentoring courses, delivered to the EFG, IGI, GeolSoc, *et al.*, with an excellent publication on mentoring. It is designed to fit the geologist's capabilities as well as into their pocket, and the book provides an introduction to the basic skills of capable questioning, active listening, building trust, personal organisation and delivering advice.

John developed his coaching skills "at the coal face", from his academic training, through his participation in mineral exploration both in Ireland and abroad, and his involvement in the delivery of executive coaching. His definitive experience came as Director of the Geological Survey of Northern Ireland. All this proficiency came to fruition in the mentoring courses that he developed and has given to a broad range of organisations and personnel. All of which yielded a solid grounding for the construction of this valuable publication.

The book is not only a useful complement for those who have attended John's courses, but it is also a valuable aid to those who suddenly find themselves becoming mentors, e.g. as junior staff are taken on and left in their charge. We have all found ourselves in this position and wished that we had some reliable guidance. Throughout this easily-read book there are exercises to help the mentor develop their skills, whilst colleagues from other professions provide useful and insightful case histories with the lessons learnt. For instance: co-operation with academia can be a crucial factor in the area of technical innovation, from medicine comes a constructive methodology of dealing with anger, and from academia the importance of positive support and a good connection between mentor and mentee.

This book covers the principles of mentoring, the composition of mentoring sessions and how to apply these in practical situations. It allows the novice mentor to develop their skills, whilst continuing to manage their inter-personal situation. This always helps to reduce anxiety when coping with a new position of responsibility and supervision.


Mentoring Scientists and Engineers
The Essential Skills, Principles and Processes
John Arthurs
CRC Press
Taylor & Francis Group

Developed from John's training manuals, this book was originally written for geoscientists and has been skilfully augmented. It expertly covers the STEM fields of science, technology, mathematics, and engineering, and it is well focussed on guiding geologists. It is highly recommended to all in charge, both as a personal volume and especially for the corporate library.

Submission of articles to European Geologist Journal

Notes for contributors

The Editorial Board of the European Geologist journal welcomes article proposals in line with the specific topic agreed on by the EFG Council. The call for articles is published twice a year in December and June along with the publication of the previous issue.

The European Geologist journal publishes feature articles covering all branches of geosciences. EGJ furthermore publishes book reviews, interviews carried out with geoscientists for the section 'Professional profiles' and news relevant to the geological profession. The articles are peer reviewed and also reviewed by a native English speaker.

All articles for publication in the journal should be submitted electronically to the EFG Office at ***info.efg@eurogeologists*** according to the following deadlines:

- Deadlines for submitting article proposals (title and content in a few sentences) to the EFG Office (***info.efg@eurogeologists.eu***) are respectively 15 July and 15 January. The proposals are then evaluated by the Editorial Board and notification is given shortly to successful contributors.
- Deadlines for receipt of full articles are 15 March and 15 September.

Formal requirements

Layout

- Title followed by the author(s) name(s), place of work and email address,
- Abstract in English, French and Spanish,
- Main text without figures,
- Acknowledgements (optional),
- References.

Abstract

- Translation of the abstracts to French and Spanish can be provided by EFG.
- The abstract should summarise the essential information provided by the article in not more than 120 words.
- It should be intelligible without reference to the article and should include information on scope and objectives of the work described, methodology, results obtained and conclusions.

Main text

- The main text should be no longer than 2500 words, provided in doc or docx format.
- Figures should be referred in the text in italic.
- Citation of references in the main text should be as follows: 'Vidas and Cooper (2009) calculated…' or 'Possible reservoirs include depleted oil and gas fields… (Holloway *et al.*, 2005)'. When reference is made to a work by three or more authors, the first name followed by '*et al.*' should be used.
- Please limit the use of footnotes and number them in the text via superscripts. Instead of using footnotes, it is preferable to suggest further reading.

Figure captions

- Figure captions should be sent in a separate doc or docx file.

References

- References should be listed alphabetically at the end of the manuscript and must be laid out in the following manner:
- Journal articles: Author surname, initial(s). Date of publication. Title of article. Journal name, Volume number. First page - last page.
- Books: Author surname, initial(s). Date of publication. Title. Place of publication.
- Measurements and units
- Measurements and units: Geoscientists use Système International (SI) units. If the measurement (for example, if it was taken in 1850) was not in SI, please convert it (in parentheses). If the industry standard is not SI, exceptions are permitted.

Illustrations

- Figures should be submitted as separate files in JPEG or TIFF format with at least 300dpi.
- Authors are invited to suggest optimum positions for figures and tables even though lay-out considerations may require some changes.

Correspondence

All correspondence regarding publication should be addressed to:
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Rue Jenner 13, B-1000 Brussels, Belgium.
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EFG broadly disseminates geology-related information among geologists, geoscientific organisations and the private sector which is an important employer for our professional members, but also to the general public.

Our different communication tools are the:

- EFG website, ***www.eurogeologists.eu***
- GeoNews, a monthly newsletter with information relevant to the geosciences community.
- European Geologist, EFG's biannual journal. Since 2010, the European Geologist journal is published online and distributed electronically. Some copies are printed for our members associations and the EFG Office which distributes them to the EU Institutions and companies.

By means of these tools, EFG reaches approximately 50,000 European geologists as well as the international geology community.

With a view to improving the collaboration with companies, EFG proposes different advertisement options. For the individual prices of these different advertisement options please refer to the table.

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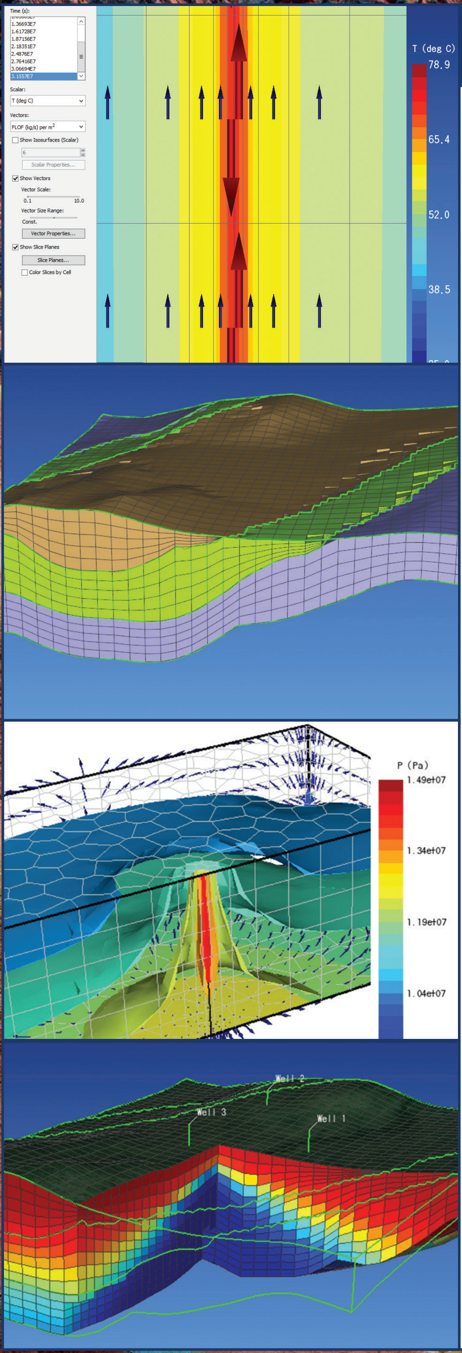

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